This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

General Library System
University of Wisconsin-Madison
728 State Street
Madison, WI 53706-1494
U.S.A.

AUSTRALASIAN ROADS.

A TREATISE, PRACTICAL AND SCIENTIFIC, ON THE LOCATION, DESIGN, CONSTRUCTION AND MAINTENANCE OF ROADS AND PAVEMENTS.

BY

JOHN MONTGOMERY COANE,
HENRY EDWARD COANE,
JOHN MONTGOMERY COANE, JUN.,

CIVIL ENGINEERS, MELBOURNE.

WITH NUMEROUS ILLUSTRATIONS.

FIRST EDITION.

GEORGE ROBERTSON & CO.
PROPRIETARY LIMITED.
MELBOURNE, SYDNEY, ADELAIDE AND BRISBANE.
1908.

McCarron, Bird & Co.,
Printers,
479 Collins Street, Melbourne.

140237
MAR 22 1910
SR
.C63

637014o

PREFACE.

THE favourable reception accorded to a short paper on roadmaking recently read before the Victorian Institute of Surveyors by Mr. J. M. Coane, and which soon ran into a second edition, and the many suggestions received by him from several parts of Australasia that the subject should be more comprehensively dealt with, have induced the authors to publish this book, which they trust may prove of service to engineers and others engaged in or connected with road work.

No comprehensive handbook is available which is applicable to Australasian climates, materials, labour and conditions generally. Works on highways, printed in English, are usually applicable to English, American, or Indian conditions, so their teachings and conclusions must be received with caution by those practising here. Every effort has been made to produce a concise, practical, and modern work applicable wholly to Australasian and partially to South African conditions. With this object in view much historical matter and a great many theoretical considerations, some of them of doubtful utility, that are to be found in most of the older text books, have been omitted. Foreign practice is referred to, where necessary, to show what is being done abroad, and what may be successfully imitated here. Complete specifications taken from actual practice have been made a feature of the book, and it is hoped that their inclusion may supply a want felt by students and by young Australasian engineers undertaking the design and supervision of road works. Costs data have been carefully arranged from the most reliable information available, and from personal experience. In using the work, however, it will be necessary ever to bear in mind that conditions and climates vary considerably over the large area covered by the Commonwealth of Australia and the Dominion of New Zealand, and that one must be careful to consider the effects of those variations in estimating costs and fixing seasons for the execution of the different classes of road work. Illustrations and tables have been freely inserted where their inclusion tends towards brevity of explanation. Automobilists will find suggestions and matters of special interest to them. Municipal councillors are referred more particularly to the chapters dealing with road economics and matters of policy and administration. Detailed examples are given showing how the financial soundness of road improvement schemes may be investigated, as it is believed that this important branch of road economics has been hitherto rather neglected, and that reports and estimates would be much more useful if they dealt with the financial side more fully than is customary at present. The authors desire to acknowledge much assistance from many printed reports, documents, and publications on the subject, and to thank those busy engineers who have so generously furnished valuable information. They hope to revise the book from time to time, and with a view to the improvement of future editions will gratefully receive and acknowledge the results of the experience of others, whether such conflict with their own practice and conclusions or not.

In this volume they have confined their attention almost exclusively to road construction, but hope in the future to deal with other engineering subjects should it appear that the difference between Australasian conditions and those of the countries where appropriate text books are issued, renders it desirable that Australasian books should be published.

J. M. and H. E. COANE.

70 Queen-street,
Melbourne, July, 1908.

CONTENTS.

CHAPTER I.

RESISTANCE TO TRACTION.

As affecting location—Axle friction—Rolling resistance—Collision—Rolling friction—As affected by wide tires—Iron and rubber tires—Resistances of various surfaces on the level—Resistance due to gradient—Power of a horse—Maximum loads hauled—Formula and table. Pages 1 to 6.

CHAPTER II.

ROAD ECONOMICS.

Money value of good roads—Criteria by which improvements should be judged—Benefits derived—Financial aspect—Haulage—Cost of haulage to farmers—Good v. bad metalled roads—Earth v. metalled roads—Economy of easy gradients—Temporary v. permanent improvements—Economy of same compared—City pavement economics—Macadam and wood pavement compared—Steel wheelways—Electric tramways on roads—Tram lines in forest country—Trees on roads—Deciduous trees recommended—Evergreen trees—Width of tires—Contract and day labour systems—Estimates of cost—How to secure improved roads—Administration—Economy—Sufficiency of funds—High standard—Modern machinery—Main routes—Systems of road administration adopted in other countries—Summary .. Pages 7 to 37.

CHAPTER III.

LOCATION OF ROADS.

Methods adopted by Romans—Most economical route defined—Effect of railway service on roads—Importance of skilful location—Location in flat country—Design of town streets—Road deviations—Loss by unnecessary length—How grades affect haulage and its cost—Maximum gradients—Topographical features—Reconnaissance—Use of aneroid—Valley roads—Roads in undulating and mountainous country—Stream crossings—Choice of gradients and curves—Watering places—Trial survey and use of tacheometer—Width of mountain roads—Final survey .. .. Pages 38 to 60.

CHAPTER IV.

EARTHWORK.

Classification of excavations—Shrinkage—Side slopes—Cross sections—Hints for construction—Banks in swampy ground—Balancing earthworks—Mode of payment—Cost of loosening—Picking and shovelling, cost of—Barrow and plank—Limitations and cost—Cost of carting and dumping—Drag scooping—Wheeled scoops, including cost—Road machines—Cost of excavation with road machines—Elevating graders—Methods and cost .. .. Pages 61 to 75.

CHAPTER V.

EARTH ROADS.

Clearing—General considerations—Sub-drainage—Cross section—Water-tables—Construction—Loaming—Channels on roads—Water breaks—Reconstruction of roads—Re-formation—Improvement and clay roads—Burnt clay roads—Improvement of sandy roads—Complete specification and schedule for clearing and formation of roads—Cost of clearing and formation—Agents of destruction—Maintenance of earth roads—Scraping—Use of split-log drag—Cost of scraping—Fencing—Complete specification for fencing .. .. Pages 76 to 95.

CHAPTER VI.

GRAVELLED ROADS.

Gravel defined—Qualities—Binding properties—Screening—Weight—Foundation—Boxing—Cross section—Width and thickness—Spreading—Rolling—Binding—Measurement—Complete specification and schedule for contract—Cost of gravelled roads—Methods and cost of maintenance and repair .. .. Pages 96 to 107.

CHAPTER VII.

ROLLERS AND SCARIFIERS.

Horse and power driven rollers compared—Types of steam rollers—Compound rollers—Weights and dimensions—Details of construction, including differential gear, etc.—Various makes described and illustrated—Motor road rollers—Motor rollers for pavements—Horse rollers—Road scarifiers—Rutty's, Henderson's, Bomford's, Morrison's—Cost of scarifying and hand picking compared .. Pages 108 to 121.

CHAPTER VIII.

ROAD METAL.

Surface depends on quality of metal—Qualifications for suitable metals—Characteristics and distribution in Australasia of rocks—Plutonic and intrusive rocks described—Granites—Porphyries—Diabase—Volcanic rocks—Basalts, etc.—Metamorphic rocks—Schists—Metamorphic granites—Quartzites—Sedimentary rocks—Sandstone—Shales and slates—Limestones—Flint—Testing road metals—Quarrying—Methods—Length of bore holes required—Hand and machine drilling—Explosives—Dynamite—Blasting gelatine—Gelignite—Rackarock—Roburite—Blasting machines—Quantity of explosive required—Volume of metal and screenings produced—Cost of quarrying—Machine v. hand breaking—Stone breakers—Jaw crushers—Rotary crushers—Screening—Portable plants—Cost of crushing plants—Cost of crushing and screening—Total cost of road metal ... ... Pages 122 to 151.

CHAPTER IX.

CONSTRUCTION OF METALLED ROADS.

Where justified—Necessity for re-location before permanent improvements are undertaken—Telford and Macadam roads compared—Modern Telford—Rock bottom roads—Modern Macadam as suited for Australasia—Reasons why old practice unsuited—Choice of methods—Foundations in clay, sand or rock—Crown required in various situations—Form of profile—Cross section of country roads—Alteration of existing levels of streets and roads—Widths of footpaths—Cross sec-

tion of town and suburban streets—Arrangement of grades of gutters and channels—Typical cross sections for roads and streets of various widths and requirements—Cross sections on sidelong ground—Cross sections of city streets—Thickness of metal in theory and practice—Sizes of stones—Necessity for screening—Measurement—Spreading—Rolling—Advantages of steam rolling—Weight of roller—Necessity for binding—Binding of the road in theory and practice—Selection and quantity of binder—How and when applied—Complete specification and schedule for metalled road contract—Cost of Telford and rock bottom foundations—Cost of metal, carting and spreading—Cost of steam rolling—Cost of horse rolling—Cost of binding—Cost of street construction itemised—Sea walls .. .. Pages 152 to 188.

CHAPTER X.

MAINTENANCE OF METALLED ROADS.

Necessity for adequate maintenance—Effect of climate on roads—Rainfall—Drought and wind—Frost—Effect of traffic on roads—Hammering of horses' feet—Abrasion of wheels—Breaking through—Rutting—Grippers on traction engines—Equal length of axles—Motor cars—Wear—Volume of traffic—Systems of maintenance—When to repair—Loosening the surface—Size of maintenance metal—Thickness of coat—Spreading—Binding and rolling—Ravelling of newly sheeted roads—Trimming flanks—Sweeping machines—Water carts—Sweeping and watering machines—Combination sweeping machines—Scraping machines—Scavengers' brooms—Tumbler and garbage carts—Total cost of maintenance—Maintenance by contract—Tarring the surface of metalled roads—Quality of tar—Applying the tar—Tar spraying machinery—Durability—Cost .. .. Pages 189 to 208.

CHAPTER XI.

TAR MACADAM AND ASPHALTUM ROADS.

Historical—Materials—Quality of tar—Mixing tar macadam—Laying tar macadam—Tarring after spreading—Cost, maintenance and advantages of tar macadam—Disadvantages of tar macadam—Bitulithic pavement—Asphalt macadam—Asphaltum roads—Classification of asphaltums—Natural rock asphalt—Val de Travers asphalt—Mastic asphalt—Trinidad asphalt—Binder or cushion coat—Wearing coat—Asphalt composition blocks—Cost, wear, life, etc., of asphaltum roads—Materials and methods compared . . . . Pages 209 to 223.

CHAPTER XII.

PAVED ROADS.

Relative merits of various surfaces considered—Durability—Foothold—Maximum gradients allowable—Cross gradients—Woodpaving—History of—Life and wear of—Timber used—Dimensions of wood blocks—Foundation—Cross section—Standard crowns—Method of laying—Slipperiness—Durability—Cost of wood blocking—Complete specification and schedule for wood blocking contract—Concrete roadways—Khleinpflaster pavement—Stone block pavement—Quality of stone—Size of—Foundation—Cross section—Laying the pavement—Grouting—Paved roads in sandy ground—Cost and durability of stone pavement—Complete specification and schedule for stone pavement contract—Brick pavement—Quality of brick foundation—Laying the bricks—Filling the joints—Cost—Steel wheelways . Pages 224 to 251.

CHAPTER XIII.

THE DUST PROBLEM.

Evil effects of dust—Source of supply—Effect of motor traffic—Suggestions for abatement of the nuisance—Dust palliatives—Fresh water—Sea water—Saline solutions—Patented mixtures—Crude oils—Coal tar products—Conclusions and recommendations .. .. Pages 252 to 259.

CHAPTER XIV.

FOOTWAYS.

Earth and gravel paths—Various pavements in use—Width of pavements—Kerbs—Specification for stone kerbing—Wooden kerbs—Tar pavement—Specification for tar pavement—Cost and durability of tar pavement—Cement matrix pavements—Cement matrix flags—Brick pavements—Natural stone flags—Asphaltum pavements—Cost and general considerations .. .. Pages 260 to 269.

CHAPTER XV.

DRAINAGE.

General principles—Drainage of country roads—Watertables—Run off from storms—Curves of rainstorm intensity—Flow in pipes—Pipe culverts—Discharging capacity of pipe culverts—Afflux at bridges and culverts—Method of calculation—Brick sewers—Reinforced concrete pipes—Masonry culverts—Timber culverts—Type drawings of same—Steel rail stringers—Pitched drains—Wood paved drains—Concrete gutters—Footbridges and carriage crossings—Gullies—Designs for same .. .. Pages 270 to 297.

CHAPTER XVI.

MOUNTAIN AND FOREST ROADS.

Improvement of steep ascents—Width and curvature of mountain roads—Passbys—Cross section—Use of retaining walls—Cross section on steep side slopes—Half tunnels—Blasting—Tunnels—Metalling—Bridges and culverts—Cost of mountain roads .. .. Pages 298 to 306.

CHAPTER XVII.

SPECIFICATIONS AND CONTRACTS.

Several kinds of contract defined—Contract papers—Hints on the preparation of same—Form of tender—Conditions of tendering—General conditions of contract, and explanation of clauses—Specimen conditions—Contract agreement—Use and form of schedule—Specifications and hints on preparation of contracts—Drawings for contracts. Pages 307 to 325.

LIST OF ILLUSTRATIONS.

Page
1 Diagram showing how resistances to traction are overcome .. 2
2 Showing incorrect location 52
3 Crossing over stream 54
4 Showing difficulties in the location of roads 55
5 Location of road approaching a gap in a main range 56
6 Showing correct and faulty location 57
7 Showing method of grading 58
8 Cross section in cutting as usually drawn 63
9 Cross section imitating natural conditions 63
10 Showing how the dip of the strata influences design 64
11 Typical longitudinal and cross sections, showing grading of road in cutting and filling 66
11A Champion road plough 67
11B Champion pavement or rooter plough 68
12 Drag scoop 70
13 Wheeled scoop in position for filling 70
14 Wheeled scoop in position for dumping 70
15 American road machine 71
15A American road machine making a fire break 72
16 Subsoil drain on road 78
17 Subsoil drain on road 78
18 Earth road, type 1 79
19 Earth road, type 2 79
20 Earth road, suited for summer traffic 79
21 Undesirable cross section 79
22 Channel and road formation combined 83
23 Road formation and channel in course of construction . to face 83
24 Road formation and channel, completed .. .. to face 83
25 Pile of wood and clay, completed, and firing begun in one of the flues .. .. to face 85
26 One section of road burnt, and a second section being fired . to face 85
27 Split-log drag for earth roads 91
28 Fence on embankment 92
29 Sketch of fence post 94
30 Sketch of rails 94
31 Teeth of tamping roller 95
32 Showing the effect of a soft foundation 98

Page
33 Bomford patent spring scarifier, mounted on 10-ton steam roller .. .. to face 109
34 Fowler-Henderson patent steam scarifier, with revolving drill to face 109
35 Marshall's steam roller .. .. to face 110
36 Roller converted to traction engine .. .. to face 110
37 Fowler's differential gear for steam rollers 114
38 First Australian-made steam roller .. .. to face 110
39 Motor roller, by Barford and Perkins .. .. to face 115
40 Water ballast motor roller, with fixed pattern hood .. to face 115
41 American motor roller .. .. to face 116
42 Reversible horse roller 117
43 Porcupine scarifier—Rutty type 118
43A Marshall's scarifier, showing attachment to steam roller 119
44 Photomicrograph of a granite section .. .. to face 125
44A Photomicrograph of a limestone section .. .. to face 125
45 Survival of early road methods .. .. to face 125
46 Hoisting cableway 131
47 Section showing quarrying operations 132
48 Plan showing quarrying operations 132
49 Section showing quarrying operations 132
50 Stationary crushing plant on level ground, with elevator, screens, bins, etc. 142
51 Stationary crushing plant on a hillside, with screens, bins, etc. 143
52 View of jaw rock crusher 144
53 Section of jaw rock crusher 145
54 View of rotary rock crusher 146
55 Section of rotary rock breaker 147
56 Portable crushing plant .. .. to face 148
56A Semi-portable bin, with elevator and screen 149
57 Section of Telford road in cutting through wet ground 153
58 Curved profile for metalled roads 160
59 Cross section of metalled country road 161
60 Cross section of town street, 66 feet wide 164
61 Cross section of 3-chain road approaching a city 166
62 Cross section of 3-chain road approaching a city 166
63 Cross section of 3-chain road approaching a city 167
64 Cross section in sidelong ground 169
65 Cross section in sidelong ground 169
66 Cross section in sidelong ground 169
67 Cross section in sidelong ground 169
68 Cross section in sidelong ground 169
69 Cross section of a city street 99 feet wide 167
70 Roman road 170
71 French road, early 18th century 170
72 Trèsaguet road, late 18th century 170
73 Modern Macadam 170

Page
74 Spreading from steel plates .. .. to face 173
75 Tarred macadamised road, Brighton, Vic. .. .. to face 173
76 Stepped profile sea wall 188
76A Ogee profile sea wall 188
76B Vertical profile sea wall 188
77 Hogg's patent road paring machine .. .. to face 198
78 First Australian-made traction engine .. .. to face 198
79 Thornycroft Stewart steam van, with water tank .. .. to face 199
80 Caink's patent jets and sprinklers 200
81 Rock asphalt carriage-way and mastic footpath 218
82 Trinidad asphalt carriage-way and footpath 219
83 Suitable profile for pavement 231
84 Cross section of wood paved street 99 feet wide 231
85 Concrete pavements for roads and footpaths 240
86 Method of laying sets on steep gradients 244
87 Paved roadway in very sandy ground 245
88 Cross section of steel trackway 250
88A Rails for steel wheelways, showing fishplates and bolts 250
88B Rails as jointed 250
89 Metal kerb protector 263
90 Wrought iron edging 263
91 Wooden kerb 263
92 Wooden kerb 263
93 Showing contour drains 272
94 Curve of rainstorm intensities 276
95 Pipe siphon utilised as drop and crossing 280
96 Timber head for drain pipe, elevation 280
97 Timber head for drain pipe, section 280
98 Monier portable culverts .. .. to face 284
99 Reinforced concrete cover of the Reilly-st. drain, Vic. .. to face 286
100 Type drawing of road culvert 285
101 Crossing for small channels 287
102 Cross section of timber culverts for country roads 287
103 Cross section of timber culverts for country roads 287
104 Cross section of timber culverts for country roads 287
105 Elevation of road bridge in timber 288
106 Cross section of road bridge in timber 288
107 Timber culvert, 12 feet ope 289
108 Wing for culvert in round and hewn timber 290
109 Typical short span timber bridge—Photo. lent by Prof. Kernot to face 290
110 Example of New South Wales highway bridge .. .. to face 290
111 Example of highway bridge in brick—Photo. lent by Prof. Kernot .. .. to face 290
112 Example of steel highway bridge .. .. to face 290
113 Cross section of pitched channel 291
114 Cross section of pitched channel 291

Page
115 Cross section of bricked channel 292
116 Cross section of bricked channel 292
117 Cross section of concrete gutter and kerb 293
118 Footbridge 294
119 Carriage crossing 294
120 Arrangement of drains at street corner 294
121 Gully trap 295
122 Cast iron gully 296
123 Cast iron inlet, without trap 296
124 Diagonal bar gully pit 296
125 Correct grading of a road ascending the face of a hill 298
126 Reverse curves, length of straight between 299
127 Showing connection between concave curves 299
128 Cross section of a mountain road, showing cross drainage arrangements 300
129 Cross section of a road in side cutting 301
130 Side cutting road, with retaining wall 302
131 Mountain road, wholly in cutting 303
132 A remarkably fine mountain road in France .. .. .. to face 304
133 Suspension bridge at Skipper's Gorge, New Zealand .. to face 304
134 Cross section of road cutting on face of cliff 304
135 Mountain road, Skipper's Gorge, New Zealand .. .. .. to face 304
136 Hawks' Crag, Buller Gorge, New Zealand .. .. to face 304

INTRODUCTION.

CORRIGENDA.

Page 21, 15th line, for "4/-" read "3/-," and for "1.61" read "1.21."
18th line, for "27.05" read "26.65."

Page 132, Fig. 49, for "Scale 30 ft." read "Scale 20 ft."

Page 186, The last sentence of § 185 refers to roads resheeted one stone thick in maintenance, not to roads under construction.

Page 187, 25th line, for "specimen" read "specification."

Page 281, 5th line from bottom insert, "head" after "velocity."

Page 325, 8th line, for "could" read "should."

public through bulletins, circulars, and reports. With a view to awakening public interest, "Good Roads" railway trains, completely equipped with modern machinery and tools, are despatched to various rural centres, where object lesson roads are constructed. The trains are sent out, not as a reflection on local engineers, but to show the inhabitants what can be done with modern appliances, including steam rollers. State assistance is granted towards road works, approved by the Commission to the extent of one-third to three-fourths of the cost; the remainder is contributed by the municipalities assisted in some cases by landholders whose properties abut on the highways proposed to be improved. There is unfortunately no uniformity of practice in the matter of carrying out the construction. In New Jersey the municipalities attend to all details; in Massachusetts the Commission orders and supervises the work, whereas in New York it is a matter of arrangement between the State engineer and the local bodies. Subsequent maintenance and repair are undertaken by the municipalities, any default in this respect being discouraged by the fact that further grants may be withheld, as provided by law. It has been argued that those who use the roads should pay the whole cost of construction and maintenance. If this objection to State aid is a valid one, then national railways and waterworks are a mistake. Surely such widely distributed benefits as those derived from good roads affect consumers and exchangers as well as producers.

Concerning the wisdom of granting State aid it must be remembered that in Australasia a majority of the population consists of city residents, who certainly possess more than one-half of the wealth of the community. If the whole cost of rural road construction is thrust upon the farmers the larger proportion of those best able to share the burden escape, although in most cases their income is indirectly derived from grazing and agriculture. As examples, we may cite stock and station agents, produce merchants, and exchangers of various sorts. The conditions obtaining in the United States are so like those under which we live that legislation similar to that which has proved successful there, but more uniform, might well be given a trial here. State Highway Commissions could undertake the construction and maintenance of main roads, especially those carrying through traffic contributing nothing towards the funds of municipalities *en route*. As owners of modern machinery, too costly for purchase by struggling shires, up-to-date Commissioners would have little difficulty in providing cheaper and better roads than are usually found to exist at present. As an example of the extended use of machinery it may be noted that since the Massachusetts Highway Commission was established in 1894, the number of steam rollers in operation throughout that State has increased sixfold, and with most gratifying results. From the setting of a higher standard of excellence, improvement of roads in general would undoubtedly result. Systematic investigation, with tests of the qualities of stone for road building, as undertaken by State Commissions abroad, has done much to cheapen and improve roads practice. The fact that automobiles, capable of rapid transit, are coming into vogue on tourist routes emphasises the necessity for better roads in mountainous districts, and suggests the desirability of co-operation with the various road authorities by the tourist departments, now established in the various States in connection with Government railways. Having thus glanced at the political aspect of road finance, it is proposed to discuss resistance to traction as a basic principle of road economics, and then to proceed to a detailed description of the methods of construction and maintenance believed to be best suited to Australasian conditions.

* * *

AUSTRALASIAN ROADS.

CHAPTER I.

RESISTANCE TO TRACTION.

1. The tractive force required to move vehicles along roads necessarily varies considerably in accordance with the condition of the surface and the gradient. The subject is of special importance in the determination of the ruling gradient as affecting location, and in the solution of problems in economics, the more important of which are touched upon in Chapter II. Resistance to traction is made up of three main forces, viz.—axle friction, rolling resistance, and resistance due to gradient.

2. **Axle Friction.**—The resistance of the hub to turning on the axle varies with the nature of the bearing surfaces as regards material and finish and with the lubricant; it is approximately proportional to the load, and is independent of the condition of the road surface and of the velocity. The coefficient of journal friction may be taken at about .015 for ordinary vehicles. The tractive resistance due to axle friction varies, of course, with the proportions between the diameters of the wheels and axle arm, as well as with the load; in the case of ordinary wagons as little as 4 to 5 lbs. per ton weight are thus absorbed.

3. **Rolling Resistance.**—This is principally due to (a) collisions with the irregularities of the surface, and (b) rolling friction as a result principally of the penetration or sinking of the tire into the road.

Collisions.—Resistance on account of pronounced obstacles such as loose stones or projecting points is equal to the horizontal force which, applied at the axle, is required to raise the wheel the height of the obstruction. The pull required to accomplish this equals $\frac{\mathbf{Wa}}{\mathbf{b}}$, where **a** and **b** in Fig. 1 represent the lengths of the arms of an ordinary bent lever. The larger the wheel the greater the leverage and the easier are obstacles surmounted.

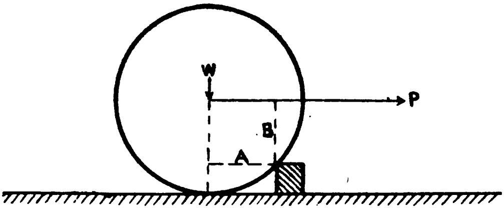


Fig. 1.

The effect of minor irregularities is rather to produce concussions and shocks, which are more pronounced at high speeds; these are considerably lessened by springs, when the velocity is over three miles per hour, and the resulting damage to the road is much reduced. Experiments show that the rolling resistance of springed vehicles with iron tires increases roughly as the cube root of the velocity on a macadamised road; with pneumatic tires the increase is negligible.

Rolling Friction.—Penetration of the tires into the road surface presents an inclined plane in front of the wheels, which has to be continually surmounted. Rolling friction is less with large wheels than with small ones, principally because the penetration is reduced owing to the greater arc of contact with the road surface; the variation for metal tires is about as the square root of the diameter. With rubber tires the increased arc of contact is due to the elasticity of the material, and not necessarily to the increased diameter of the wheel, which does not sink into the road.

Wide Tires.—The effect of an increase in the width of tires is to reduce the penetration, and thus to lessen the resistance due to rolling friction. Experiments with self-recording dynamometers have proved conclusively that wide tires materially reduce the draft under all but two conditions, viz.:—

(a) On hard and incompressible surfaces the width makes but little difference in traction, the advantage, if any, being slightly in favour of narrow tires.

(b) When the surface is sticky or extremely dusty, and the bottom hard, mud or dust is raised in greater quantities by wide tires, and the draft is somewhat increased by their use.

The relative merits of wide and narrow tires with rules for determining appropriate widths under various conditions are more fully discussed in § 25, Chapter II.

4. **Iron and Rubber Tires.**—Experiments show that a solid rubber tire offers slightly less resistance to traction than an iron one if the road is sticky, very irregular, or covered with snow, but that it is inferior if the surface is hard and smooth. In average cases metal and solid rubber are about equal, though there is less vibration with the latter. By the adoption of pneumatic tires, tractive resistances are reduced from 15 to 30 per cent. for slowly moving vehicles, and as much as 50 per cent. in those propelled at a rapid rate. The worse the surface the greater the economy of pneumatics. With pneumatic tires the tractive resistance varies but little with the speed, i.e., the advantages of pneumatic tires over those of iron are greater with fast moving vehicles than with those propelled at slow rates.

5. **Tractive Resistance on the Level.**—Table I. shows the average total of all the above-mentioned resistances to the continued traction of ordinary vehicles on various level surfaces with narrow and wide tires respectively. The figures are compiled from the results of the most reliable tests yet conducted.

TABLE I.

TRACTIVE FORCE, in pounds per ton, required to keep a wagon and its contents in motion on a level road at the rate of about 2½ miles per hour.

DESCRIPTION OF SURFACE.	WIDTH OF TIRES.	
	2″.	6″.
	Lbs.	Lbs.
Sand, deep and loose	450	400
Clay, deep and sticky	600	450
Earth road, clay, dry on top but spongy beneath	500	400
,, 3″ to 4″ of sticky mud, firm beneath	300	350
,, fairly muddy	200	180
,, loose dust 2″ deep, firm beneath	100	115
,, well consolidated	85	70
Gravel road, well consolidated	68	60
Metalled road, covered with loose stones and rutted	120	110
,, ,, in fair order	64	60
,, ,, dry and smooth	40	40
Stone pavement, in good order	35	37
Wood ,, ,, ,, tar dressed ...	32	34
Steel tramplate, clean and without flanges ...	25	—
Steel rails in street tram lines, clean	22	—

6. **Resistance Due to Gradient.**—When ascending an incline the tractive force required to lift the load is additive to, but quite independent of, that required to overcome all the resistances on the level. Grade resistance is approximately equal to the gross load divided by the co-tangent of the angle of inclination—in other words, the horizontal distance in which the rise is unity. For example, a load of one ton on a grade of 1 in 20 requires a pull of $\frac{2240}{20}$ = 112 lbs. to overcome the grade resistance—i.e., to prevent the vehicle from rolling backwards.

7. **Power of a Horse.**—The pull that a horse can exert depends principally upon the strength, weight and training of the animal, upon the speed, and upon the hours of work. Australian draught horses are particularly sturdy, and one of average capacity, weighing about 1500 lbs., can be relied upon to exert, when the foothold is good, a pull of 160 lbs. for the

greater part of eight hours per day at walking pace. Twice this force can be exerted without injury for two hours out of eight, while on very short pinches 640 lbs. is within its capabilities. When starting heavy loads, or in emergencies, the maximum effort approximates one-half of the weight of the horse. Horses can generally be made to exert a slightly greater individual pull when working singly than when yoked in teams. It must not be forgotten that the horse has to raise his own weight, in addition to that of the load, when climbing a hill.

8. Maximum Loads Hauled.—The gross load drawn by a horse on any gradient can be approximately calculated by the formula.

$$L = \frac{t - \frac{W}{R}}{T + \frac{2240}{R}}$$

where L = load, inclusive of vehicle, in tons.
t = tractive pull exerted by one horse in lbs.
W = weight of the horse in lbs.
T = tractive force required to haul one ton on a level. (See Table I.)
R = horizontal distance in which the rise is unity.

Example.—Compute the load that a good horse, weighing 1500 lbs., may be expected to haul on a smoothly metalled road (T = 40 lbs.) on a 1 in 20 gradient when exerting a pull of 240 lbs.

$$L = \frac{240 - \frac{1500}{20}}{40 + \frac{2240}{20}} = 1.08 \text{ tons.}$$

Table II., computed by the above formula, gives the gross loads that a horse can draw on the level and on various gradients. It will be noticed that the smoother the road surface the greater the reduction in the load that can be taken on a gradient. The greater relative importance of easy gradients when the road is hard and smooth, as compared with one with a rough or soft surface, is thus rendered apparent.

TABLE II.

Gross load in tons hauled when the horizontal pull t = 160, 320 or 640 lbs. respectively.

T = tractive resistance in lbs. per ton on the level.

Note that it takes a staunch and heavy draught horse to accomplish a horizontal pull of 640 lbs. for even a few minutes. See § 7.

GRADIENT.	Earth Road, Muddy.			Earth Road, Well Consolidated.			Gravelled Road, Well Consolidated.			Metalled Road, Rough Surface.			Metalled Road, in Fair Order.			Metalled Road, Smooth Surface.			Wood Pavement, in Good Order.		Steel Tram Rails, Clean.	
	T = 200 lbs.			T = 85 lbs.			T = 68 lbs.			T = 100 lbs.			T = 64 lbs.			T = 40 lbs.			T = 32 lbs.		T = 20 lbs.	
	t=160	t=320	t=640	t=160	t=320	t=640	t=160	t=320	t=640	t=160	t=320	t=640	t=160	t=320	t=640	t=160	t=320	t=640	t=160	t=320	t=160	t=320
Level	.80	1.60	3.20	1.88	3.77	7.53	2.35	4.70	9.41	1.60	3.20	6.40	2.50	5.00	10.00	4.00	8.00	16.00	5.00	10.00	8.00	16.00
1 in 100	.65	1.37	2.82	1.35	2.85	5.84	1.61	3.39	6.94	1.19	2.50	5.12	1.69	3.55	7.27	2.34	4.92	10.08	2.68	5.65	3.45	7.26
1 in 50	.53	1.18	2.49	1.00	2.23	4.69	1.15	2.56	5.40	.90	2.00	4.21	1.19	2.66	5.60	1.53	3.41	7.18	1.69	3.77	2.00	4.46
1 in 30	.40	.98	2.15	.69	1.69	3.69	.77	1.89	4.13	.63	1.54	3.37	.80	1.94	4.24	.96	2.35	5.13	1.03	2.52	1.16	2.84
1 in 25	.34	.90	2.00	.57	1.49	3.31	.63	1.65	3.67	.53	1.37	3.05	.65	1.69	3.77	.77	2.00	4.46	.82	2.13	.91	2.36
1 in 20	.27	.79	1.81	.43	1.24	2.87	.47	1.36	3.14	.40	1.15	2.67	.48	1.39	3.21	.56	1.61	3.72	.59	1.70	.64	1.86
1 in 18	.24	.73	1.72	.37	1.13	2.66	.40	1.23	2.90	.34	1.06	2.48	.41	1.26	2.96	.47	1.45	3.40	.49	1.52	.53	1.65
1 in 16	..	.67	1.61	.29	1.00	2.43	.32	1.09	2.62	.28	.94	2.27	.32	1.11	2.68	.37	1.26	3.03	.38	1.31	.41	1.41
1 in 14	..	.59	1.48	.22	.87	2.18	.23	.93	2.34	.20	.82	2.05	.24	.95	2.38	.26	1.07	2.66	.27	1.11	.29	1.18
1 in 12	..	.50	1.33	..	.72	1.90	..	.77	2.02	..	.68	1.79	..	.78	2.05	..	.86	2.27	..	.89	..	.94
1 in 11	..	.45	1.25	..	.64	1.74	..	.68	1.85	..	.61	1.66	..	.69	1.88	..	.75	2.07	..	.78	..	.82
1 in 10	..	.40	1.16	..	.55	1.59	..	.58	1.68	..	.52	1.51	..	.59	1.70	..	.64	1.85	..	.66	..	.70

CHAPTER II.

ROAD ECONOMICS.

9. As a general proposition it may be stated, without fear of contradiction, that good highways possess a considerable monetary value. In cities and towns, smooth and comparatively dustless roads are looked upon as essential to the comfort and health of the inhabitants, regardless, within reasonable limits, of their cost.

To rural roads the same arguments do not apply with equal force, because the question of ways and means enters more largely into the consideration, especially in sparsely settled areas. Whether it is better for a community to content itself with barely passable roads, on which a minimum amount of money is spent, or to submit to somewhat increased taxation to secure the additional financial advantages of better highways, is a question on which there is too often no fixed public policy. It has been contended, and very reasonably, that sparsely populated municipalities in mountainous country cannot, unaided, support the burden of maintaining long lengths of road, not to speak of their construction. In such cases outside assistance in the form of Government grants is generally voted, but not to the extent that it might be with all fairness. It is to the under-populated, struggling municipalities, the inhabitants of which are really pioneers in the subjugation of our forests, that the system of State aid outlined in the introductory chapter is more particularly applicable. Considering the case of a farming community in which the country has already been fairly well roaded, but in which there is still scope for improvement, what policy should be pursued in the matter, and by what criterion should suggested improvement schemes be judged? Up-to-date railway managers profitably invest large sums of money in regrading, eliminating sharp curves, and for laying down heavier rails, so that train loads may be increased and operating expenses reduced. The very same policy should be applied to the improvement of existing highways; in fact, it is the duty of every municipality to reduce for the farmer his haulage expenses by carrying out needful improvements. In this connection it should be remembered that the benefits derived from good roads are more apparent during periods of financial depression, when prices are low, and the cost of haulage large in proportion to the margin of profit. Most enlightened and progressive taxpayers, bearing in mind the financial and other advantages of good roads, will favour consistent extension and improvement as rapidly as funds permit. The question then arises, to what extent is taxation justifiable? In other words, will it pay to expend a given sum to produce certain anticipated results?

In every community there is to be found quite a considerable proportion of the ratepayers who, knowing that they will have to bear their share of the cost, are opposed to expenditure on public works in general and roads in particular. To this class, who may sometimes be useful as curbing rash expenditure, the financial and social advantages of good roads are by no means apparent. To them the agitation spreading throughout the civilised world in favour of improved rural highways is viewed with a feeling of positive distrust. There are admittedly two sides to this important question, and as a contribution towards its solution it is now proposed to investigate the advantages of good roads, and to outline methods by which the cash savings directly attributable to them can be approximately determined. Where it can be shown that the losses incurred by ratepayers due to bad roads would more than suffice to pay for the making and maintenance of good ones, the most sceptical would surely admit the wisdom of undertaking improvements. Where the expenditure does not indicate a corresponding saving, the improvement as a business proposition is not sound, and can be justified only on social or educational grounds. Apart from the financial aspect, it can scarcely be denied that smooth roads are desirable for reasons analogous to those which induce people to build comfortable homes.

10. Benefits Derived.—Stated briefly, the principal advantages of good roads over bad ones, apart from their social advantages to which it is difficult to assign a money value, are—

1. They render possible increased loading and faster travel, and thus, by economy of time and force in transportation, reduce the cost of haulage.
2. They reduce wear and tear of horses, vehicles and harness, all of which cost money.
3. They permit traffic at all times, and thus enable farmers, firewood carters, sawmillers, and others, not only to find profitable employment the year round, but to market their commodities when the highest prices prevail, irrespective of season. In this connection the effect of good roads in equalising traffic, and in reducing quite appreciably the number of railway trucks required to transport products, should be noted.
4. Good roads are a great factor in the encouragement of tourist traffic, so profitable to the inhabitants of attractive resorts.
5. As a result of all the advantages mentioned, the market value of real estate is enhanced, more especially in dairying and market gardening districts where perishable products must be transported, summer and winter alike.

11. Financial Aspect.—The determination of the economic value of road improvements is at all times a difficult problem that does not admit of precise solution. Clearly, where the expenditure of large sums of money is involved, something more than mere guesswork is required. Attempts have been made to show the value of good roads by a variety of methods, and some very extravagant figures have been produced in not a few otherwise excellent publications. For the consideration of this important question, information on the following points must be available:—

(a) Cost of improvement.
(b) Maintenance charges.
(c) Cost of cartage.

As an approximate test of the pecuniary benefit, if any, likely to accrue, it is wise to prepare comparative statements showing the estimated annual charges both before and after improvement; the difference shows the profit or loss to the community, and provides a basis for discussion. Working on these lines, and confining the discussion to roads in rural districts only, we shall take into account the direct cost of haulage, no credit being given for savings due to reduced wear and tear, or for social and educational advantages arising from facilities for rapid transit by light vehicles. With the limitations just mentioned, the cost of haulage will be investigated, and some practical advantages will be considered in detail.

12. **Haulage.**—Social conditions are so variable that any average figures that might be given would be likely to prove misleading if relied upon in the consideration of particular cases. Probably the best means of arriving at the cost is to divide the working expenses by the number of tons hauled. For example, assume that firewood is to be carted 2 miles to a railway station, along a metalled road in fair condition, but with a number of pretty long 1 in 30 gradients against the loads, 6 horse teams in wagons being employed. Reference to Table II. shows that each draught horse can be relied upon to haul for long periods .8 ton, i.e., the gross load, inclusive of the vehicle, may be set down at 4¾ tons; assuming the wagon to weigh 1¼ tons, the net load is about 3½ tons. The average rate of travel in both directions will not exceed 2½ miles per hour, and an hour and a half should be allowed for loading, unloading, and minor delays, making a total of, say, 3 hours per trip. On the basis of three round trips, the average weight transported per day would be about 10½ tons over 2 miles, equal to 21 ton miles, at a cost of, say, 30/-, or 1/5 per ton mile. Except, perhaps, in the case of dairymen, market gardeners, or others engaged in pursuits demanding frequent journeys to market, sometimes with small quantities of perishable produce, the cost of cartage of full loads only should be considered. It would be manifestly absurd to base estimates on the cost of carrying wheat or firewood in parcels of 1 cwt. at a time, when the conditions of the roads and the strength of the teams would allow of several tons being taken with

ease. When back loading in any quantity can be secured, the cost per ton would be lower than in cases where the wagons are compelled to return empty.

13. **Cost to Farmers.**—Farmers employing their own teams can, as a rule, cart their produce at a cheaper rate than teamsters would charge them. Many argue that because this class of work is undertaken in the slack season, when men and horses would otherwise be idle, the cost to them is merely nominal. The fact that employment could very often be found in the service of others, if not in profitable work on their own farms, is quite overlooked. The more energetic farmers often secure work for their horses during the off season in road and channel making, in wood carting, dam sinking, or such like. To them time taken up in carting farm produce is time lost from profitable outside work, and its value must be estimated at the rate earned when engaged on the latter. To those who do not engage in work outside their own purely farming operations, and whose horses would otherwise be idle, the cash outlay on account of cartage is admittedly much lower than it would be if the cartage were done by contract. The horses would have to be kept in any case, but it is only on the smallest of farms that drivers' wages and the price of additional feed for working teams would not be an extra, chargeable solely to transportation; again, horses will age and die whether worked or not. It is too often forgotten that, while men and horses are thus engaged, outside labour employed in haulage of material for farm buildings, fences, etc., and in their erection, is being hired at current wages. Admitting that in many places outside work cannot be obtained, and granting that farmers with their own teams, by working long hours, do effect a saving in the cost of haulage, it is assumed in the following investigations that the cost to them is two-thirds of the price obtained by teamsters for similar work.

14. **Good v. Bad Metalled Roads.**—Taking as an example a badly rutted metalled road leading to a township, the ruling gradient on which is 1 in 50; produce and firewood to the extent of 10,000 tons per annum are conveyed, mostly in six-horse wagon loads, the average haul being 4¼ miles, three-

fifths of the whole being carted by farmers with their own teams. Construction originally costs £600 per mile, but, through neglect and the expenditure of only £20 per annum on maintenance, the road has been practically destroyed. Assume that by the expenditure of £400 per mile in reconstruction, including strengthening structures too weak to carry the increased loads that will follow the improvements, and £60 per year thereafter for repairs and maintenance, a smooth surface can be provided. Will it then pay to make the suggested improvements?

Consulting Table II., we find that a fair gross load for a six-horse team, working every day on the rough road, is 5.4 tons. The net load may be set down at 4¼ tons, and, as only two trips can be made per day, the weight transported will not exceed 8½ tons, or, say, 36 ton miles. Assuming the expense of carriage by teamsters to be only 9d. per ton mile, the cost to farmers would be two-thirds, or 6d.

Existing Road—	£
Interest, 4½ per cent., and sinking fund, 1½ per cent. —6 per cent. on original cost of £600	36
Maintenance	20
4000 ton miles at 9d.	150
6000 ton miles at 6d.	150
	£356

On the improved surface the gross load per trip by Table II. may be increased to 9.2 tons, say 8 tons net, or 68 ton miles per day, and the cost of haulage reduced to 4¾d. and 3¼d.

Improved Road—	£
Interest, etc., on original cost, 6 per cent. on £600	36
Interest, etc., on cost of reconstruction, 6 per cent. on £400	24
Maintenance	60
4000 ton miles at 4¾d.	80
6000 ton miles at 3¼d.	80
	£280

These figures show a net saving to the community of £76 per mile per annum, neglecting the many incidental advantages not allowed for in the calculation. It should be noted, in addition, that the existing road would, under heavy traffic, and with the small amount of money available for maintenance, soon become almost impassable. The worse the road, the stronger and heavier the vehicles required to withstand the strain of violent jolts. As every pound saved in tare is a pound increase in the useful load transported, quite considerable savings are attributable to smooth roads in this respect.

15. **Earth v. Metalled Roads.**—It has been strongly urged that the making of earth roads is a mistake, and that in all cases gravel or metal should be used. As applied to city or suburban highways, the contention is correct, and does not admit of argument. When one reflects, however, on the fact that in much of our wheat growing country even medium gravelled roads cost about £600 per mile, sometimes much more, and that the cost of maintenance is high, it becomes obvious that in most of our shires the capital outlay would be prohibitive, except for main roads leading to townships and railway stations, and carrying concentrated traffic. For about eight months of the year in our semi-arid districts, the earth roads are good if scraped up at slight cost (see § 86), whereas gravelled or metalled roads, rutted during the winter, are rough and uneven during the rest of the year unless maintained at very considerable expense. Horses working on earth roads need not generally be shod unless kept constantly going, and they are less knocked about and last longer on earth than on metal. It is not contended that in rich districts such as the western one of Victoria, or the Richmond, N.S.W., where there is generally plenty of basalt or other fairly good road material available, metalled or gravelled roads are not practicable and preferable. We do hold, however, that many earth roads must and should remain as such, and that the closest scrutiny of the financial conditions should be made in every case before metalling is decided upon. By way of example, consider the typical case of a mile of earth road, in a level wheat-growing country, over which 2000 tons of produce are carted each year by farmers with their own teams.

One-half of the quantity is carted when the roads are hard at a cost of 5d. per ton mile, the balance when the roads are heavy for 10d. per ton mile. The first cost of the earth formation was £80 per mile, and £10 per annum is spent in maintenance. A gravelled road can be provided with the expenditure of £500 per mile, and if £30 per annum is set aside for repairs and maintenance the cost of haulage to farmers at all seasons will not exceed 4d. per ton mile. Under existing earth conditions the cost per annum, in round numbers, is about:—

Six per cent. interest and sinking fund on £80, say	£5
Maintenance	10
1000 ton miles at 5d.	21
1000 ton miles at 10d.	41
Total	£77

After improvement the estimated charge on the community is as follows:—

Six per cent. interest and sinking fund on £80, say	£5
Six per cent. interest and sinking fund on £500, say	30
Maintenance	30
2000 ton miles at 4d.	33
Total	£98

The figures show that the savings in cartage charges do not warrant the proposed expenditure, neither would they until the traffic over the road was almost trebled. Approaching the subject from another aspect; assume a county divided into 320 acre farms, with roads a mile apart. Metalling of the roads in one direction only would involve half a mile of construction for each farm, at a cost of, say, £300. At £7 per acre the value of a holding would be £2240, and the cost of the road not less than 13½ per cent. of the capital value of the land. In view of the fact that it is more costly to maintain metalled roads than earth formations, such an assessment could not be borne.

16. Economy of Easy Gradients.—The cost of cartage varies, approximately, inversely as the loads that can be taken each trip. That is to say, if the loads must be reduced by one-half, the cost is about doubled. Table II. shows, approximately, at a glance, the relative loads that can be drawn when the horizontal pull is 160, 320 and 640 lbs. respectively. The question of the economy of proposed road deviation frequently crops up in practice, and, more often than not, is decided offhand without close investigation. In many instances the answer is obviously in favour of diversion, but in others the closest scrutiny is required before a satisfactory conclusion can be reached. The subject is more fully discussed in §§ 37 and 38, Chap. III., where detailed solutions of typical cases will be found. In the matter of gradients it must always be remembered that the rougher or softer the road surface the less noticeable the effect of hills. Bearing this in mind, the necessity for easy gradients on metalled roads that will, presumably, be kept in good order is apparent.

17. Temporary v. Permanent Improvements.—Before deciding on the design of structures, pavements, or improvements of any sort, the question of economy should be fully gone into; economy not only in first cost, but in the long run. When considering the relative economy of improvements, it is necessary to take into consideration, not only the interest payable on the first cost, but, in addition, the amounts that must be set aside to maintain the works in perpetuity. The financial aspect of the question must include the following:—

(1) Interest on first cost; (2) equal annual payments to a sinking fund for the extinction of the debt at the end of some term corresponding with the life of the structure, or with a period fixed by statute within which payment must be made; (3) maintenance charges; (4) equal annual payments to a depreciation or renewal fund which, invested at compound interest for a number of years corresponding with the life of the structure, will provide, at the end of the term, the amount required for rebuilding. Table III. gives the percentage of the first cost to be paid each year when the rate of interest earned is known, and when it is desired to extinguish the debt in a given number of years, interest being compounded yearly. This table is useful for calculating the amount of either sinking or renewal fund.

TABLE III.

PERCENTAGES PAYABLE in equal Yearly Instalments to a Sinking or Renewal Fund to mature in a given number of years.

Number of Years to Maturity.	RATES OF COMPOUND INTEREST EARNED.			
	3 per cent.	3½ per cent.	4 per cent.	5 per cent.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
8	11.25	11.05	10.85	10.47
9	9.84	9.64	9.45	9.07
10	8.72	8.52	8.33	7.95
11	7.81	7.61	7.42	7.04
12	7.05	6.85	6.66	6.28
13	6.40	6.21	6.04	5.65
14	5.85	5.66	5.47	5.10
15	5.38	5.18	4.99	4.63
16	4.96	4.77	4.58	4.23
17	4.60	4.40	4.22	3.87
18	4.27	4.08	3.90	3.55
19	3.98	3.79	3.61	3.27
20	3.72	3.54	3.36	3.02
21	3.49	3.30	3.13	2.80
22	3.27	3.09	2.92	2.60
23	3.08	2.90	2.73	2.41
24	2.90	2.73	2.56	2.25
25	2.74	2.57	2.40	2.10
30	2.10	1.94	1.78	1.51
35	1.65	1.50	1.36	1.11
40	1.33	1.18	1.05	.83
45	1.08	.95	.83	.63
50	.89	.76	.66	.48
55	.73	.62	.52	.37
60	.61	.51	.42	.28
65	.51	.42	.34	.22
70	.43	.35	.27	.17
75	.37	.29	.22	.13
80	.31	.24	.18	.10
100	.16	.12	.08	.04

TABLE IV.

Present Value of an Annuity of £1; *i.e.*, the capital sum which, if invested at a given rate of interest, will produce an annual income of £1 for the given term of years.

Years.	Rates of Compound Interest Earned.			Years.	Rates of Compound Interest Earned.		
	3 per cent.	4 per cent.	5 per cent.		3 per cent.	4 per cent.	5 per cent.
5	4.5797	4.4518	4.3295	25	17.4131	15.6221	14.0939
6	5.4172	5.2421	5.0757	26	17.8768	15.9828	14.3752
7	6.2303	6.0021	5.7864	27	18.3270	16.3296	14.6430
8	7.0197	6.7327	6.4632	28	18.7641	16.6631	14.8981
9	7.7861	7.4353	7.1078	29	19.1885	16.9837	15.1411
10	8.5302	8.1109	7.7217	30	19.6004	17.2920	15.3725
11	9.2526	8.7605	8.3064	32	20,3888	17.8736	15.8027
12	9.9540	9.3851	8.8633	34	21.1318	18.4112	16.1929
13	10.6350	9.9856	9.3936	36	21.8323	18.9083	16.5469
14	11.2961	10.5631	9.8986	38	22.4925	19.3679	16.8679
15	11.9379	11.1184	10.3797	40	23.1148	19.7928	17.1591
16	12.5611	11.6523	10.8378	45	24.5187	20.7200	17.7741
17	13.1661	12.1657	11.2741	50	25.7298	21.4822	18.2559
18	13.7535	12.6593	11.6896	55	26.7744	22.1086	18.6335
19	14.3238	13.1339	12 0853	60	27.6756	22.6235	18.9293
20	14.8775	13.5903	12.4622	65	28.4529	23.0467	19.1611
21	15.4150	14.0292	12.8212	70	29.1234	23.3945	19.3427
22	15.9369	14.4511	13.1630	75	29.7018	23.6804	19.4850
23	16.4436	14.8568	13.4886	80	30.2008	23.9154	19.5965
24	16.9355	15.2470	13.7986	100	31.5989	24.5050	19.8479

Example.—Compare the economy of a timber bridge, costing £1000, the estimated life of which is 20 years, with that of a steel structure costing £1800, and possessing a life of, say, 60 years. The bridges would be equally effective, but the annual maintenance charges, which include painting, minor repairs, and an allowance for fire risk, are £35 and £20 respectively. The rate of interest on borrowed money, and for the investment of sinking and renewal fund instalments, is assumed to be 4 per cent. per annum. The money is to be borrowed under conditions which necessitate repayment within 20 years, the life of the structure, in the case of the timber bridge; while for the steel one the repayments can be extended over 40 years, as in the case of the Victorian "Local Government Act." Calculate first of all the annual charges, as under:—

ANNUAL CHARGES.

Timber Bridge.		Steel Bridge.	
Interest on £1000 at 4 % ..	£40	Interest on £1800 at 4 % ..	£72
Sinking fund, 20 years at 3.36 % on £1000	33.6	Sinking fund, 40 years at 1.05 % on £1800	18.9
Maintenance, including provision for fire risk	35	Maintenance, including provision for fire risk	20
Renewal fund, 20 years at 3.36 %	33.6	Renewal fund, 60 years at .42 %	7.5
	£142.2		£118.4

The tabulated charges appear to indicate a yearly saving of £23.8 in favour of the more permanent structure, but it must be noted that the comparison holds good for the first 20 years only. At the expiration of that period the first cost of the original timber bridge will have been paid off on the maturity of the sinking fund, and the cost of an entirely new one provided from the accumulations of the renewal fund. Subsequently, the two first-mentioned items drop out of the timber bridge calculations, and, although the renewal fund instalments continue to provide for rebuilding at the end of the 40th and 60th year, the yearly payments are reduced to £68.6, whereas the steel bridge charges continue, as tabulated, till the end of the 60th year. In such cases the comparison of annual charges of varying duration is by itself no criterion of economy, and nothing short of capitalisation of the annual payments will suffice. By this is meant the present value of the annuities payable to renew and maintain the structure for a given term; in other words, it is the capital sum which, if invested at compound interest on the inception of the works, would produce an annual income equal to that required to meet the charges during their currency. The present value of £1 for any number of years at a given rate of interest can be found by inspection of Table IV.; the present or capital value of any other sum, for the same term and rate, is found by simple multiplication. Taking the case in question, let us proceed to capitalise the annual payments required for the upkeep of the respective structures during 60 years.

CAPITALISATION.

Timber Bridge.		Steel Bridge.	
First cost	£1000	First cost	£1800
Present value, £35 per annum for 60 years' maintenance..	792	Present value, £25 per annum for 60 years' maintenance..	566
Present value, £33.6 per annum for 60 years, contributed to renewal fund ..	760	Present value of £75 per annum for 60 years' renewal fund	170
	£2552		£2536

The result is still slightly in favour of the steel bridge.

It has been argued, however, that, by including renewal charges in the considerations, a heavy burden is being laid on the present generation to save a future one from expense. While this is a matter of policy, and as such is open to argument, the renewal fund should never be omitted when the ultimate economy of structures is in question. Taking the above examples and omitting, contrary to correct principles, the renewal charges, we find that the wooden bridge costs £108.6 per year, while the annual expense of the steel one is £110.9 per annum, for the whole term of 60 years in each case. Keeping in view the greater risk of destruction of the wooden bridge, and the resulting inconvenience in the event of such destruction, the slight saving of £2.3 per annum is negligible. As circumstances will, of course, vary greatly, and as each case must be considered on its merits, it is impossible to lay down any hard and fast rule, especially as there is always the hope that there may be improvements in materials and methods. Generally, however, we believe that it will be found better business to use fairly permanent materials than to employ inferior ones, the matter involving questions beyond those of mere finance.

18. City Pavement Economics.—It has been shown that, in the matter of country roads, the objective is a surface sufficiently hard and durable to reduce haulage charges, consistently with economical expenditure, and smooth enough to render travelling comparatively easy. In cities, the questions of comfort and luxury, as affected by freedom from dust, noise, and slipperiness, enter very largely into the design of highways. As an instance, it may be noted that, although granite sets on a concrete base make the most durable and, in the long run, most economical pavement, the exacting demands of modern city life preclude the use of such material on the grounds that it is noisy, slippery, and destructive to horses' feet. It will then be readily perceived that, when attempting to adjust the economic value of pavements, local necessities and conditions must be given full weight. Where the traffic is very heavy, experience has demonstrated that broken stone is not sufficiently durable to be economical, because of the high cost of maintenance; as yet, however, by far the larger proportion of city roadways are merely macadamised. As alternative to ordinary broken stone for important city streets, the selection of more or less desirable materials is at present limited to wood blocks, asphaltum, and tar macadam. The relative merits of the several pavements being considered in Chapter XII., the discussion, for the present, will be confined to the question of economy of cost and upkeep, and an attempt will be made to show when, under given conditions, it pays to construct a more permanent surface than can be produced with broken stone. English engineers writing upon the subject variously estimate that when the annual cost of maintenance of metalled roads exceeds from 1/6 to 2/6 per square yard, it is in the end cheaper to employ some more durable material, such as wood. The French authorities proceed to pave their *Routes Nationales* when the traffic exceeds 1500 colliers, or single horse loads, per day. The figures, while giving an approximate idea of the practice obtaining elsewhere, cannot be regarded as particularly valuable to those working under such widely divergent conditions as are met with in Australasia. The relative economy of pavements is best determined on lines similar to those laid down in § 17. Reliable estimates of the cost of upkeep are essential to an intelligent study of road economics, and the absence of detailed official records of road maintenance charges is a matter of great regret. It should be the duty of every road engineer to tabulate the sums expended from time to time, on each length of road under his jurisdiction, with an estimate of the volume of the traffic thereon. Such information, in permanent and accessible form, would enable the engineer to select the most economical pavement with certainty. See § 194. While it is impossible to detail every case that might arise in practice, it is believed that the following example illustrates the principles fully enough to enable any problem in pavement economics to be similarly investigated. Take the typical case of a macadamised road, costing 3/- per square yard to construct in the first instance, and the annual expenditure of 2/- per square yard thereafter to maintain the road perpetually in a condition practically equal to new. It is proposed to make a financial comparison of this with a wood-paved surface, the first cost of which is 16/- per square yard, including concrete foundation; the annual maintenance charges are estimated at 5d. per square yard for 20 years, at the end of which time reblocking will be required at a cost of 10/- per square yard. The concrete foundation will not deteriorate, and its renewal need not be provided for. The capital cost, borrowed on 4 per cent. debentures, must in each case be liquidated within 20 years by equal annual payments to a sinking fund invested at 4 per cent. per annum compound interest.

ANNUAL CHARGES. (For the First 20 Years.)

Macadam.	Pence.	Wood Pavement.	Pence.
Interest on first cost, 4 % on 3s.	1.44	Interest on first cost, 4 % on 16s.	7.68
Sinking fund, 20 years, 3.36 % on 4s.	1.61	Sinking fund, 20 years, 3.36 % on 16s.	6.45
Maintenance	24.00	Maintenance	5.00
Renewal fund	—	Renewal fund, 20 years, 3.36 % on 10s.	4.03
	27.05		23.16

The advantage lies in favour of wood pavement, which, in view of its undoubted superiority, should under the circumstances be selected in preference to macadam. Although, at present, we are concerned with the merely financial aspect, it must not be forgotten that each class of pavement has its particular limitations, more especially as regards foothold on gradients. The merits and demerits of each, with special reference to Australasian conditions, are discussed in §§ 234 to 237, Chapter XII.

19. **Steel Wheelways.**—Steel tram plate lines can be recommended when the traffic is heavy and of a particular class of slowly moving, long distance, trains of wagons. They would be useless in city streets, and are not really serviceable on any but rural or semi-rural main roads, or on roads leading to some particularly busy factory to which there is a great deal of vehicular traffic. The introduction of this class of track on some of the main roads radiating from Melbourne for the accommodation of heavy market wagons has been successful and convenient. Paving between the plates is desirable, as there being generally only one line on each highway, observance of the rule of the road

causes frequent turning out of vehicles and consequent injury to the wheels, especially where the plates are flanged. Pair horse teams cannot conveniently use a track made with smooth plates, and when the macadamised portion of the road is in anything like good order, the tram lines are more often than not abandoned in its favour. Tram plate lines are unsuitable for rapidly moving vehicles, and to such are generally an obstruction, besides being somewhat unsightly. These ways, when laid on perishable timber, as described in § 267, cost approximately £2000 per mile. Although wear and tear of plates and pitchers of good quality is slight, trouble arises through "cold rolling" of flat plates and temperature variations. Difficulties in these respects are said to be overcome by the use of the new form of trackway described in § 267. When the plates are clean, traction is light, and provided the grades are moderate, very heavy loads can be taken, but when dirty the draught is rather heavy and not much less than on a macadamised road of smooth surface.

Concerning the economy of tram plate lines possible advantages include:

(a) Increased loads due to reduced traction; (b) savings in annual upkeep, inclusive of maintenance and interest charges. As regards reduced traction, it must be remembered that the advantage of the smooth surface decreases rapidly as the gradient increases. On lines laid down for the specific purpose of accommodating heavy traffic, confined entirely to the tram line itself, quite considerable savings, due to reduced tractive resistance, would, of course, be made. After years of observation the conclusion is reached that market gardeners, at any rate, do not largely increase their loads beyond what could be taken over a smoothly metalled road, and that, though the roads are saved a great deal of wear and tear, the saving on this account is not very great. Further information concerning the construction of steel trackways will be found in § 267.

20. Electric Tramways on Roads.—Tramways serve the public best by following the main thoroughfares. They should not, however, be allowed to take complete possession of the road, and when concessions are granted to private companies, carefully drawn up agreements are essential if friction between divergent interests is to be avoided. Both lines and grades should be determined by the municipality, on the advice of its engineer, and the constructing authorities should be compelled to rigidly conform to these. Provisions should be made at the same time for raising or lowering pipes, culverts, etc., where necessary, free of expense to the council. Included among the principal matters to be definitely prearranged are: guaranteed frequency and regularity of service, charges for sectional and through fares, with a provision for revision of same at stated intervals. Under the terms of a concession the tramway property and goodwill usually revert to the municipality at the expiration of a term of years. The interests of the ratepayers should be safeguarded by rigid requirements as to constructional details and by the provision of a sinking fund whereby the original capital charges are to be liquidated within the currency of the agreement. The line of way should be laid on one side of the centre, so as to allow for subsequent duplication, a contingency never to be lost sight of. All necessary changes in the road levels should be carried into effect when the tram line is under construction. Subsequent alteration would be very expensive, should it involve the practical rebuilding of the permanent way at the council's expense. The nature of the pavement between and alongside the rails should be mutually agreed upon before the tramway is commenced. Sheet paving, such as asphaltum or tar macadam, is not so satisfactory as wood, stone or brick paving. Block paving can be easily lifted and re-used when repairs to rail bonds, joints or sleepers are required. Sheet asphaltum requiring a concrete base is not readily removed, whereas tar macadam is rather poor construction needing close attention. More often than not, tramway authorities are required to maintain and construct the roadway between rails and, say, 18 inches on each side. The advisability of such an arrangement, adopted as a method of taxation, is open to serious question. In the tramway interests the road repairs are likely to be starved, or with the best of intentions the work of maintenance may be ineffective, owing to the absence of skilled assistance in this particular branch. Experience in our larger cities, as well as on suburban tracks, is proving the wisdom of maintenance being carried out by the municipality, but at the expense of the tramway.

21. Tram Lines in Forest Country. — Privately-owned wooden rail tram lines in connection with the timber industry are commonly laid down, at comparatively small cost, in forest country where horses are utilised for haulage, and where the highways are impassable to heavily laden vehicles in the winter. Discarded railway track is occasionally used in place of wooden rails both on account of its greater durability and the reduced tractive resistance of the iron or steel rail. Such lines usually lead to railway stations and follow the roads as closely as gradients permit.

For the opening up of densely wooded hilly country, tramways with either metal or wood rails might, in many places, be constructed, and if necessary operated, by municipalities. Where the cost of an adequate metalled road would be prohibitive in the first instance, such means of communication and transport would prove of inestimable service to pioneer settlers, and could, by judicious management, be made to pay its way. It is not suggested that tramways should supplant roads, which are always necessary; they might, however, suffice for all practical requirements in the early stages of settlement, especially in localities where, during the rainy season, earth roads are practically impassable.

22. Trees on Roads.—In residential streets, 40 feet wide and over, trees are nearly always desirable for the shade they afford, on account of the improved appearance foliage imparts to the thoroughfare, and as dust arresters. Trees act as a medium for the transfer of moisture from the soil to the atmosphere through their leaves, and in this way help to maintain the air in a condition of reasonable humidity. The chief objection urged against the presence of trees in the streets is that they keep the road wet and sloppy by excluding sunlight. In wet localities they certainly are sometimes a distinct disadvantage, particularly on highways running in an easterly and westerly direction. The same objections do not apply to roads running approximately north and south, on all parts of which the sun necessarily shines for several hours each clear day. With a view to minimising troubles on this score it is well, as a general rule, to plant none but deciduous trees where much dull or misty weather is experienced. In summer, shade is distinctly advantageous to roads, as it helps to prevent an excessive drying out of moisture and consequent disintegration of the surface, with concomitant dust and discomfort to travellers. That trees are of great utility as wind and, consequently, as dust arresters is undoubted. Some varieties extend their roots almost horizontally, and do considerable damage by lifting and deranging paths and gutters. This trouble can be eliminated to a large extent by selecting trees whose roots grow downwards rather than horizontally. Tree planting, though unnecessary from a strictly engineering point of view, makes the surroundings attractive and thereby has a distinct financial value. Other conditions being equal, purchasers of houses will undoubtedly select the streets in which well grown plantations throw their grateful shade. In some European countries utility is further combined with attractiveness by planting edible fruits, notably mulberry trees, the leaves of which are gathered as food for silkworms. The difficulty of protecting the products from depredation is a serious one, however, and it is generally better to confine the selection to purely ornamental trees, including those mentioned below.

With a few exceptions deciduous trees are more suited to our conditions than the native evergreens. Thorough drainage is necessary to the successful growth of trees; where the ground is at all retentive a continuous trench 2 feet to 2 feet 6 inches deep and about 6 feet wide should be excavated and refilled partly with suitable soil, not only to afford drainage but to allow room for the roots to spread. The planting should be done in the Autumn and the trees should not be nearer than say 30 feet for planes or elms. If planted closer, trouble will certainly arise when they approach maturity. Protection in the form of tree guards is absolutely necessary for some years after planting. The more important trees, with leading characteristics, are mentioned below.

23. **Deciduous Trees.**—The *Oriental Plane* is probably the best shade tree, and given good soil and plenty of space is about the best to plant in most situations. The plane tree has a clean stem that sheds its bark each year and stands severe pruning remarkably well. Of the *Elms* the Guernsey elm is said to be the best on the whole. The American elm is useful for wide streets, but requires too much room in narrow ones. For poor and stony soils the cork-barked elm is highly recommended. It, unlike some

other varieties, thrives in exposed positions. All elms are subject to insect pests which fortunately do not attack the plane.

The *English Oak* does not thrive at its best in hot districts, and owing to trouble caused by the attacks of scale and red spider it is very little planted nowadays. In the cooler districts the oak does better.

Poplars are free from insect attacks, are easily grown, but some varieties send up innumerable suckers which are objectionable. The silver poplar grows tall and is suited for narrow streets. For wider streets the Canadian poplar, which spreads more, is recommended. *Limes,* also called *Lindens,* grow best in cool districts, but are not recommended for warm localities.

Horse Chestnuts, though very handsome, simply won't stand hot winds, and should never be planted where the temperature rises very high.

The *Sycamore, English Oak* and *Maple* are suitable for planting in moderately cool districts and in most parts of New Zealand.

Acacia will grow rapidly in almost any soil, and its flowers are very effective. The foliage soon withers, however, and the roots send up numbers of suckers.

24. Evergreen Trees.—One of the most suitable trees for hot and dry districts is the well-known *Pepper.* Few trees create so much litter as *Pinus Insignis.* For this reason, and because of their straggling nature, as well as the enormous size to which they grow, they should never be planted on a road less than say 3 chains wide. With the exception of some of the eucalypti, very few of our native trees are suitable. *Wattles* are too short lived for the purpose. *Sugar Gums* do very well, but must be well pollarded, or they will soon grow too high to afford any sort of shade. The *Bastard Mahogany* of Victoria is said to be a better foliage tree.

Flowering Gums are handsome, but are of stunted and irregular growth, and cannot be recommended.

Moreton Bay Fig creates a great litter and can only be used on very wide streets.

Grevillia resist the heat and drought well and can be alternated with pepper trees in dry districts. Although classed as an evergreen, this tree makes a great litter with fallen leaves.

25. Width of Tires.—Several Australasian States have passed laws relating to widths of tires for heavily laden vehicles. In others no regulations have as yet been framed, presumably because the importance of preserving roads, on which millions of pounds have been spent in construction, is not fully realised. The general introduction of wide tires is advocated on two grounds—firstly, because the particularly destructive action of narrow rims is avoided, and, secondly, on account of the increased loads that can be taken under nearly all conditions. The rolling effect of broad tires is admitted by all practical engineers, many of whom contend that vehicles so provided act as road menders rather than road breakers. The difficulty is to persuade the average ratepayer that appreciable advantages are to be gained by their use. Objection is raised on account of the cost of new wheels and in the erroneous belief that wide tires increase the draught. As regards the first contention it does not appear to be generally known that the width of waggon tires can be cheaply and effectively increased by shrinking on wider steel bands, which can be further secured to the rims by bolts or clips if desired.

Numerous tests, the results of which are summarised in § 5, point conclusively to the material advantages of wide over narrow tires in the matter of tractive resistance. Recapitulating briefly, it may be stated that on earth roads narrow tires show better results, in respect to ease of haulage, only when the road surface is either in a condition to "pick up" readily, or else very dusty, while the bottom is sound and hard. Under all other conditions the result is very much the other way. On metalled roads of average quality wide tires reduce the draught quite appreciably, though on the very best macadamised roads tractive resistance is independent of the width. That wide tires preserve roads of all kinds from rutting must be admitted by all reasonable persons. Reviewing legislation on the subject, it may be noted that in the Victorian "Local Government Act 1903," section 569, provision is made for limiting the loads, inclusive of the weight of the vehicles, to 4½ cwt. per half inch width of bearing surfaces of tires, or 9 cwt. per inch, nothing being said about the diameter of the wheels. It is true that Macadam recommended the limit of 9 cwt. per inch, but experience has led later authorities to a very different conclusion. The trend of modern legislation is to fix a maximum of about 5 cwt. per inch for wheels of average diameter, and those who have closely observed the effect of heavily loaded lorries, on even good metalled roads, will almost certainly agree with the lighter load. Sub-section 2 of the clause quoted above enables the Governor-in-Council, in "special circumstances," to reduce the weight. Thus a lorry with 2½ inch tires, and wheels just about 3 feet in diameter, without infringing the law, may carry 3 tons 10 cwt. of loading, its own weight of about 1 ton making up the allowable load on the wheels. This is undoubtedly far too much for basalt or equivalent material, while for limestone, slate or earth roads it is simply ruinous. Lorries such as described rarely carry more than 3½ tons, so that as the law is now administered the width of tire provisions are practically useless, more especially as tires round off at the edges after a few months use so as to reduce the effective width by at least half an inch. It may be mentioned that the weight on the wheels of an ordinary ten ton steam roller is under 5 cwt. per inch, or little more than half the load allowed for by law as above. The Western Australian Act regulates the width by fixing the proportions between diameter of axle and breadth of tire as under:—

When diameter of axle arm is 2 inches, the width of tire must not be less than 3 inches.

When diameter of axle arm is 2¼ inches, the width of tire must not be less than 3½ inches.

When diameter of axle arm is 2½ inches, the width of tire must not be less than 4 inches.

When diameter of axle arm is 2¾ inches, the width of tire must not be less than 4½ inches.

When diameter of axle arm is 3 inches, the width of tire must not be less than 5 inches.

Although this method accomplishes the object sought with some degree of satisfaction, the principle on which it is based cannot be regarded as particularly scientific. In districts where earth roads prevail, or where only weak metal can be got, six inches would appear to be the least width that should be adopted for tires of vehicles intended for heavy loading; instances can be cited of wheels about a foot in width being used with great advantage for carting heavy loads of timber, wool, etc., over boggy country.

A practical example of the recognised advantages of wide tires is furnished in the road laws of New Jersey, U.S.A., where a rebate to the extent of 4/2 per annum on municipal taxation is allowed for every wheel in use 4 inches wide and over.

Recent English legislation, designed to regulate the width of tires for motor wagons, provides very properly for a variation in the width of tires with the diameter of the wheel, the minimum being fixed at 5 inches. Table V. shows the widths required with steel tires; the regulations do not apply to pneumatic tires, or to those of a soft or elastic material.

TABLE V.

Showing Width of Steel Tires in Inches for Motor Wagons in Great Britain.

Weight of Load per Wheel, including Vehicle.		Diameter of Wheel.							
		24-in.	30-in.	36-in.	42-in.	48-in.	54-in.	60-in.	66-in.
Tons.	Cwt.								
1	10	5½	5	5	5	5	5	5	5
1	14	0	5½	5	5	5	5	5	5
1	18	7	6	5½	5	5	5	5	5
2	0	7½	6½	5½	5	5	5	5	5
2	5	8½	7	6	6	5½	5	5	5
2	10	9½	8	7	6½	6	6	5½	5
2	15	10½	8½	7½	7	6½	6½	6	5½
3	0	11	9½	8½	7½	7½	7	6½	6
3	5	12	10	9	8½	8	7½	7	6½
3	10	13	11	9½	9	8½	8	7½	7
3	15	14	12	10	9½	9	8½	8	7½
4	0	15	12½	11	10	9½	9	8½	8

The following empirical rule (original) gives the minimum width of wagon tires deemed desirable on roads surfaces. It will be noted that the width is varied inversely as the square root of the diameter of wheel.

Minimum desirable width of tire in inches

$$= \frac{\text{gross weight per wheel of vehicle and load}}{\sqrt{\text{diameter of wheel in inches}} \times c}$$

where c = 60 for earth roads,
c = 85 for metalled roads,
c = 130 for wood blocking or paved roads.

26. Contract and Day Labour Systems.—In road operations a very large proportion of the total expenditure is due to labour, and a small proportion to the actual materials. Taking, for example, the case of a country metalled road it will be noted that, while the value of stone *in situ* is trifling, the cost of quarrying, hauling, spreading, etc., as well as the preparations of the road bed, depends almost entirely on the labour conditions. Bearing this fact in mind the necessity for skilful arrangement whereby labour can be economised by modern appliances, and otherwise directed to the utmost advantage, must be obvious. In this respect executive engineers have almost unlimited scope for the exercise of sound judgment, and have it within their power to waste money or effect substantial savings for their employers.

Work, the nature of which cannot be predicted or measured with accuracy, is best undertaken by day labour. Likewise, when competition is anything but keen, it is often cheaper to carry out construction by administration, without the intervention of a contractor. Street cleansing and maintenance come under this category, and the almost universal experience is that work of this character is most economically attended to by a trained staff of labourers. Trained labour is essential to efficiency, and close supervision is required for the reason that men, the world over, are apt to work less energetically for corporations than for individuals. The success of day labour depends in a great measure on the overseer in charge, who, if wise, will train his men thoroughly and arrange for reasonably permanent employment provided that each does a fair day's work. As an alternative to day labour, construction can be let on the principle of actual cost, plus a fixed sum agreed upon before the work is put in hand. This arrangement holds out few inducements to scamp the work, but urges the contractor to hurry the job through without delay so as to be free to tender for other contracts. Cost, plus a percentage, tends towards good but expensive construction. Works of considerable magnitude are, however, generally best carried out by contract at scheduled rates on the lines indicated in Chap. XVII. It is, in every case, very necessary for the engineer to prepare a detailed estimate of cost of all works tendered for. If this is neglected there is always the possibility of unduly high offers being accepted, it being well known that contractors often tender at very high rates on the chance of their bid being the lowest, and of its acceptance without critical investigation. The piece work or butty gang system is only a modification of the contract system; in that case each man is a contractor paid at a special rate fixed by the engineer. On this subject the reader is referred to Chap. XVII.

27. **Estimates of Cost.**—The cost of road works depends principally on the class of labour available, on the current rate of wages, on the price of materials, on the designs, and upon the mode of construction adopted. Estimates based on technical journal reports of works somewhat similar in design are likely to prove misleading, unless the conditions under which the work was carried out are accurately known. To assist in the preparation of estimates, cost data relating to all important branches of road work will be found in this book. It is to be understood that the figures given refer, unless otherwise stated; to the actual cost, including proportion of plant maintenance, of works carried out under average Australasian conditions in accordance with the specifications given herein. The prices of material are given in each case as far as practicable. Wages for various classes of labour have been allowed for as scheduled in Table VI. Contractor's profit varies from say 10 per cent. on materials to 20 per cent. on labour, depending, of course, on the nature of the works and the risks incurred. Generally, it must not be forgotten that before applying the figures to particular cases the local conditions must be closely studied and necessary modifications made.

TABLE VI.

AVERAGE AUSTRALASIAN RATES OF WAGES, SUBJECT TO MODIFICATIONS ACCORDING TO LOCALITY AND CONDITIONS.

CLASS OF LABOUR.	Wages per Day of Eight Hours.	Wages per Hour.
Labourer, scavenger, and sweeper ..	7/-	-/10½
Foreman labourer	7/6	-/11¼
Pitcher setter	9/-	1/1½
Carpenter	10/-	1/3
Steam roller driver	10/-	1/3
Driver labourer, with horse in cart, watercart, scraper or sweeping machine ..	11/-	1/4½
Driver labourer, with two horses in wagon, watercart, roller or scoop	15/-	1/10½
Driver labourer, with four horses in wagon, roller, road machine or other implement	25/-	3/1½
Driver labourer, with six horses in roller, road machine or other implement ..	35/-	4/4½

28. How to Secure Improved Roads.—The experience of this and other countries shows conclusively that to attain good roads close attention must be given to the following matters of policy, among others.

Administration.—While it is the duty of municipal councils to decide matters of general policy, all details of road construction and maintenance should invariably be at the discretion of specially trained and duly certificated engineers, personally responsible for them, but unhampered by multitudinous clerical duties, or by interference in any shape or form. Adequate remuneration, with security of tenure of office during good behaviour, is essential to satisfactory results. In Victoria, as well as in some of the other States, shire engineers are paid such low salaries that changes of officers, with the consequent losses of efficiency, are so frequent as to quite demoralise works and schemes for improvement. Insecurity of tenure is most unsatisfactory to engineers who, in the execution of public duties, cannot avoid conflict with individual interests, and it must be regarded as one of the weak points of most local government legislation, calling for early rectification. Although the principle is recognised in some quarters, a mistake is frequently made by assuming that the exclusive services of an engineer are in all cases required by a shire. When the annual expenditure is comparatively small it is true economy to employ a consulting engineer of proved ability, on fees or commission, or alternatively for two or more councils to jointly employ a first-class professional man at a good salary.

Economy.—Economy in location and construction, consistently with requirements, can only be attained on expert advice. While flimsy construction is never economical, a vast amount of money can be wasted, not onlv in unskilful design, but in the unwise selection of material and methods, as well as in the control of contractors and works generally. Engineering blunders are costly, and best avoided by placing the management in competent hands.

Sufficiency of Funds.—One of the principal functions of municipal councils is to provide sufficient funds for the construction and maintenance of roads as well as for drainage works, street lighting, tree planting and other operations. In this connection it is a matter of regret that some councils, not fully realising their responsibilities, and relying for assistance on government grants, are loth to impose taxation sufficient to meet obvious requirements.

High Standard.—A high standard of excellence should be set in road works. The standard demanded by any particular community depends very largely on what that community has been accustomed to. Once a district has enjoyed good roads for a year or two the degree of excellence demanded is always being raised, and the people become rapidly more critical. Roads in one district regarded as excellent, may in another be considered execrable.

Modern Machinery.—The necessity for modern machinery and appliances cannot be over-estimated, particularly where labour is scarce. Municipalities whose revenue is small labour under a disadvantage in their inability to purchase the requisite plant for economical working. Combined ownership among several adjacent shires makes the burden lighter, and has been found to work satisfactorily.

Main Routes.—Main roads carrying through traffic should be nationalised for the same reasons that railways are made a charge on the State, and not on the particular communities served by individual branch lines. The national roads of France, Germany, Austria, Switzerland and a number of the American States have proved so successful that we, in Australasia, need have no hesitation in adopting the principle.

29. The following brief resumé is useful as showing the systems of road administration adopted in a few of the more representative of the older settled countries. It will be noted that the trend of modern legislation is towards compelling the wealth of cities to contribute to the upkeep of rural roads. Considerable light can, it is believed, be thrown on the policy of State aid by a study of the experience and methods here recorded.

France.—The French have adopted a very vigorous policy in the matter of highways, with the result that their roads are, to-day, probably unequalled for general excellence. They are divided into three main classes, viz.:—

(1) National roads connecting all the important points in the Republic, constructed and maintained by the national Government. The total length of the *Routes Nationales* is about 24,000 miles.

(2) Departmental roads, maintained by local taxation, one-third of the cost of construction, in the first instance, being provided under a system of State aid.

(3) Neighbourhood roads, constructed and maintained by local taxation. France is divided into eighty-seven departments, in each of which the national roads are under the control of an engineer-in-chief, who is assisted by a staff of engineers, each of whom has charge of one arrondissement. Conductors, responsible to the assistant engineers, are in authority over groups of workmen, each individual being told off to attend to several miles of road. Departmental road work is supervised under practically the same system, but by an independent staff. Neighbourhood roads are generally under the control of the national road officers. The necessarily large staff of engineers required to direct the maintenance of the 345,000 miles of roads intersecting France receive special training at the School of Bridges and Roads, after which they enter on practical work of gradually increasing importance.

Switzerland.—State aid is granted to the most important highways, which are built and kept in order by the Cantons, corresponding to State Governments, who contribute liberally to their cost and repair, and, generally, bear the whole cost of necessary bridge work. Less important roads are directly controlled by the municipalities under a system of local taxation. The Swiss highways have reached a high degree of perfection.

Germany.—The highways are divided into State, Provincial and Local roads, with State aid, on lines practically identical to those adopted in France. Extensive tree-planting is a feature of German highways.

Austria.—The main roads, very heavily built, are entirely maintained by the State. Provincial roads are constructed and maintained by the provinces out of general funds, while District and Community roads are supported by local taxation under municipal control.

Great Britain.—The roads are supported by parishes, or by counties, under local government laws somewhat similar to those of Australian States. A strong agitation is, however, on foot for the nationalisation of main roads on lines corresponding with French practice.

United States of America.—American roads are for the most part under the supervision of local bodies, modelled in the first instance on English practice. In response to the good roads agitation, systematic State aid is being introduced in quite a number of the States, and it is expected that the whole of them will fall into line in this respect within the next few years. The practice obtaining in some of the States is briefly outlined below. The proportion furnished by the Government varies between one-third in New Jersey and three-fourths in Massachusetts. State aid is generally disallowed on all but gravelled or metalled roads. New York practice, however, is to vote assistance to road works of all descriptions, including earth formations.

New Jersey.—As the law stood in New Jersey in 1907, any council may petition for the gravelling or metalling of particular lengths of road, plans and specifications for the construction of which must be submitted to the Roads Commissioner. Towards the construction of roads approved and carried out by the Commissioner, the State contributes one-third of the total cost; the council finds the balance, but has power to require one-tenth of the total to be borne by the abutting owners. Roads improved under the State aid system are maintained solely by the councils within whose territory they are situated. Failure to keep any such road in repair involves the withholding of further monetary aid until such time as the defects are remedied.

New York.—The Higbie-Armstrong Act of the New York State Legislature, passed in 1898, provides for permanent improvement and construction of the more important highways (outside of cities or villages) by the State. The State and the county each pay half the costs in the first instance, but eventually the county and town share the expenditure, so that in the final apportionment the State is liable for 50 per cent., the county 35 per cent., and the town 15 per cent. of the outlay. Towns are, in America, subdivisions of counties corresponding with our parishes, and must not be confused with villages or cities. Maintenance is undertaken by the State engineer, but the town authorities contribute £10 per mile per annum, as well as the cost of maintaining and repairing bridges having a span of five feet or over; any excess over this amount is paid by the State.

Less important highways are constructed, repaired, and maintained under the Money-System Act, under the direction of a Highway Commissioner, elected biennially by the town. The State contributes £1 for every £2 raised for highway purposes, but the annual subsidy is limited in amount to one-thousandth part of the assessed valuation of the town, except in the cases of poorer rural communities, when, if the capital valuation is less than £200,000, there is no limitation. Inspections are made by State officials, and default in maintenance is penalised by withdrawal of further grants, until the omission is rectified. Legislation of 1906 provides for the application of £1,000,000 per annum for ten years, in order to meet State contributions to improved highways.

Massachusetts.—The State is divided into cities and town with a system of local government. A Highway Commission, consisting of three members appointed to study roads and road materials and to carry out constructional work, has done invaluable service. The commission decides on petitions for the improvement of roads, and carries out the construction, bearing the whole cost, with the proviso that one-fourth of the total amount, with 3 per cent. interest, is to be repaid by the county within six years. Roads so built become State highways, and are maintained by the Commission. The cost of repairs and maintenance, up to £10 per mile per annum, is charged against the town or city in which the road is located. The actual expenditure is very often in excess of this amount, the balance being paid by the State.

30. Summary.—The wisdom of thoughtful investigation into road problems cannot, it is contended, be too deeply impressed on those charged with municipal management. As regards rural roads, enough has been written in this chapter to show the absolute necessity for economy of the right sort, more especially as regards the design of structures, so often responsible for a large proportion of the expenditure in first cost and upkeep. It may be added that further scope for appreciable savings lies in a judicious selection of material suited for the foundation and wearing coats respectively, in the introduction and use of modern machinery, and in the reduction in the widths of metalled roads, where the traffic is light. All these points are considered in detail in subsequent chapters. City street economics have been approached from a somewhat different aspect, due weight being given to the more exacting requirements of urban life. Much remains to be done by municipal effort regarding width of tire provisions, and in the regulation of traction engine and motor car traffic. In connection with other subjects touched upon, further and more detailed information regarding design, construction and cost will be found in succeeding chapters.

CHAPTER III.

LOCATION OF ROADS.

31. The policy adopted by the Romans was to lay out their roads in perfectly straight lines, irrespective of gradients, in the belief, no doubt, that the shortest route was the best. Early writers advanced the theory that roads to be agreeable to travel should be winding. While this is so for pleasure drives, such considerations should in new countries be entirely ignored, and all roads should be located from an economic standpoint. The route should be as direct and, subject to drainage requirements, as level as possible. The most direct route, however, is not necessarily the straightest, but is the shortest compatible with suitability of gradient, curvature, &c. In fact the location of a road should be based on the same financial principles as should govern every engineering undertaking. That is to say, the most economical road is the one which, while properly serving the requirements of the greatest number of people, requires a minimum expenditure in interest on first cost, without undue maintenance expenses afterwards. The road that costs least in the first instance may not be the most economical; first, because the extra annual maintenance charge on a faulty road may exceed the difference between the interest charges for good and for bad construction; and second, because, as will be shown in §§ 37 and 38, the increased cost of haulage on a short road with steep grades may exceed the interest charge on the cost of the extra length necessary to secure moderate grades.

It has been suggested that the introduction of railways puts an end to road troubles; this is a mistaken idea, except, perhaps, as to what are known as main roads, for a railway gives an impetus to a district, and improved access to stations is almost invariably required.

The importance of skilful location at the outset cannot be too strongly urged, because every error made at this stage imposes, until rectified, a perpetual tax upon the suffering public. The engineer should, before deciding on the route, satisfy himself that absolutely the best location has been secured. To enable this to be done, sufficient time for investigation must be allowed, and adequate remuneration provided for the work. The question of the remuneration of the locating surveyor is too often a stumbling block in the matter of road selection. A moderate sum judiciously spent in preliminary surveys may save hundreds or even thousands of pounds in capital cost, and secure for all time a better highway.

32. **Location in Flat Country.**—In very flat districts roads should follow as far as possible the highest ground, not only because it is the driest, but because the best material for road-making is almost invariably found on the ridges. Usually in the plains there is a wide choice of routes, but natural obstructions, such as watercourses, swamps, depressions, very stony patches, or ground very likely to be flooded, must be avoided. Generally, the road may be placed without special reference to its longitudinal slope, as drainage will be provided by the watertables, and cross drainage by culverts at suitable intervals. The rule, so often quoted in text-books, providing a slope of at least 1 in 125, cannot always be applied, however desirable that may be. In farming districts, where the holdings vary in extent between 200 and 320 acres, the rectangular system of road design, with intervals of about a mile each way, usually gives satisfaction, and a width of one chain may be adopted. It has been common in the past to sell land on paper designs made in the office before survey. This is a dangerous practice, which has led to much faulty location. In no case should the surveyor be hampered by any rigid paper definition, but should always be at liberty to select the best routes. Main lines of communication between important centres should be kept open by the reservation of oblique roads of two or three chains in width. The surveyor should provide for watering places at intervals on all main roads, and when dealing with unalienated lands should make the necessary reservations for public dam sites. In districts where irrigation is likely to be carried on, or where stock and domestic supply channels may be wanted, it is desirable to increase the width to 150 or 200 links, as it has often been found convenient to place distributory or spur channels on

roads. In flat inland pastoral districts it has been the practice, in Western New South Wales and Queensland, to reserve stock routes up to a mile in width along main lines of travel. These are extremely useful where large mobs of sheep and cattle are driven, and must of necessity find feed by the way. In hilly and undulating country the widths are smaller. Where railways are available it has been found that stock is usually trucked, and that the wide roads fall into disuse. In fact, in such districts cheap grass is generally the drover's objective.

33. **Town Streets.**—For business streets where trees are to be planted a width of one chain is barely sufficient, whereas, except in large towns, 150 links is rather too much, being inconvenient for shopkeepers, and involving unnecessary expense for maintenance. The somewhat unusual width of 125 links is very suitable, giving room enough for a satisfactory carriage way, ample footpaths and two rows of trees. Fifty feet is the minimum width allowed in Victoria for public roads under the Health Act, but except for residential streets with little or no through traffic, this is too little, especially if electric tramways are among the possibilities of the future. The case of the city of Wellington, New Zealand, where the main streets are mostly 75 links wide, and where double lines of electric tramways have been laid down, is a good example of the inconvenience of such narrow streets. No doubt when these were laid out, electric tramways were not thought of, and the guiding consideration was the complete utilisation of the very limited area of reasonably level ground available. In Auckland, on the other hand, most of the principal city streets are 90 ft. wide, of which the carriage way absorbs 60 ft. and two footpaths 15 ft. each. Those who have been engaged in the design of sewerage systems for towns will realise the necessity for lanes giving access to the rear of the premises, and the great savings that can be effected when such are available. Who knows how common sewerage systems may become in the future? For this reason alone, apart from their general utility, rights of way should be provided in the design of every new township; a desirable width is 25 links, but 12 ft. can be made to serve. Township design in flat or slightly undulating country requires most careful

consideration as regards surface drainage. Until deep level sewers are provided, the drainage from houses, and the run-off from roads, roofs, &c., must all be carried to an outfall by way of the public streets. With this in view, it is most important that drainage ways should be reserved along all valley lines, however shallow the depressions may be. No township in a flat district should be laid out without first ascertaining by levels that the roads and lanes are so designed as to provide drainage for every block. In fact, the laws of several of the States require plans of all private property subdivisions to be submitted, with detailed levels of the land, for the approval of the municipal authorities. Some of the towns on the alluvial plains of several of the Australasian States are far distant from any river, creek, or gully, and their sewerage, possibly even their surface drainage, involves artificial lifting of some sort. The Shone system of pneumatic ejectors seems to be one of the best for this class of work, and care should be taken to provide room for air-compressing stations, ejector pits, &c., when such towns are being first laid out. In new districts only does the problem of locating long lengths of road confront the engineer. In older settlements he is more often called upon to relocate and regrade comparatively short sections of existing roads, portions of which can be improved with advantage. It must not be forgotten, however, that absolute relocation is sometimes better than tinkering with small diversions. In the various States and colonies there is plenty of both these classes of work to be undertaken in the near future. The considerations governing a wise selection are the same in either case, and will be discussed from a practical point of view in the succeeding pages of this chapter.

34. **Road Deviations.**—The importance of correct location has not in the past been fully realised, and the result has been that many roads have been badly placed. While it is true that this important branch of engineering has often been slighted by placing the work in the hands of incompetent men, the fault in many cases is not chargeable to the surveyors, but to circumstances beyond their control. In new countries tracks are often pushed out in advance of permanent settlement, and necessarily along routes naturally passable, or, at any rate, requiring little more than clearing to enable teams

to get along somehow. Very often the only practicable natural surface track is along the undulating crest of some ridge or spur with grades up to 1 in 4 and steeper. When the road survey in connection with the selection or alienation of Crown lands is undertaken, the surveyor is generally faced with a very difficult problem. The dray track of the pioneer, now developed into a much-used road, must, with all its faults, be reserved for public use, perhaps as a bridle path only, until money can be found for the construction of a properly graded highway. In the early days the usual practice was, without following blindly every track, to lay out all but the most important in such positions as to be traffickable with but a small amount of side cutting. For this reason ridge and valley roads were very often adopted against the better judgment of the surveyor simply because there was, under the regulations by which he was guided, no other course open to him. In Victoria the Surveyor-General, Mr. J. M. Reed, I.S.O., has introduced a much-needed reform in the system of road survey, and insists on the grading and pegging of the best routes through Crown lands in all cases where the traffic is likely to warrant the construction of a road. Existing tracks through blocks are reserved for public use until the local authorities can make the roads. The best location can be decided only after close investigation and survey of the country to be traversed. Before describing the field work it is proposed to deal with the relations of length and gradient to volume of traffic, and to discuss certain fundamental principles involved.

35. **Loss by Unnecessary Length.**—As already stated, a road between any two points to be connected should be as short as possible, provided the gradients and curvature are satisfactory. The monetary loss involved by an unnecessary increase in the length of a road can be approximated when the volume and cost of haulage is known. Take for example the case of a road between two points 8 miles long by one route, and by another 6 miles; the total rise and fall is the same in each case, gradients are well within the limits allowed, curvature is satisfactory, and the cost of construction and land compensation is £250 per mile by either route. The cost of cartage independent of loading and unloading (see §§ 12

and 13) is, say, 6d. per ton-mile, and 4000 tons of freight are carted per annum. The loss per annum involved in the adoption of the longer route, or, in other words, the saving that may be effected by the shorter is then—

Interest 4½ per cent. and redemption fund charges, say 1½ per cent., a total of 6 per cent. on £500, the cost of 2 miles of road	£30
Maintenance of 2 miles of road for a year, say,	50
8000 ton-miles hauled at 6d.	200
	£280

This estimate of £280 is a conservative one, as neither the haulage on the return journey of the empty wagons, nor that of light vehicular traffic in either direction is included. Of the annual amount £80 is directly chargeable to the road works; the balance of £200 represents the loss to teamsters and farmers using the road. Many landowners are under the impression that carting, if done by their own teams at a season when their horses and men are not busy at other work, costs them practically nothing. This is not correct, though there is an element of truth in the idea. See § 13. Mr. W. E. Bush, A.M. Inst. C.E., City Engineer of Auckland, has kindly given us, among other interesting information, particulars of a notable enterprise undertaken to save a long detour by providing a practically level connection across a deep gorge known as the Cemetery Gully, between Symonds-street and Grafton-road, both important thoroughfares on spurs running parallel to the gorge. Across this valley, at a total cost of about £40,000, the city council is building a reinforced concrete bridge, 950 ft. total length, with one central span, probably the longest in the world in concrete, of 320 ft. The other spans range from 76 ft. 6 in. to 35 ft. The greatest height of roadway above bed of gully will be 145 ft., and the width of bridge will be 36 ft., made up of a 24-ft. carriage-way and two 6-ft. paths. This fine and expensive structure is considered by this enterprising municipality to be warranted by the connection it will afford between two flourishing districts now effectually severed by the long gorge lying between them.

36. How Grades Affect Haulage.—As explained in Chapter I., the effect of an inclination on a road is to increase the tractive force necessary to haul a given load. The increase due to gradient is independent of the surface of the road. The better the surface the greater the necessity for keeping the gradients down. For example, reference to Table 2 shows that on wood blocking a 1 in 20 gradient reduces the load that can be drawn on the level by one horse when exerting a uniform pull of 160 lbs. to the extent of 88 per cent., whereas the corresponding reduction on a muddy earth road is only 66 per cent. The old theory that travel on undulating roads is less fatiguing to horses than on the level has been proved fallacious. There is no doubt that a minimum of exertion is required on a perfectly level stretch, and that the introduction of gradients does increase the draught.

37. How Grades Affect Cost of Haulage.—Just at what degree of inclination the cost of haulage is materially increased is a somewhat difficult question, but a fairly definite conclusion may be arrived at as follows, taking the case of an undulating road, following generally a level line, with but small hollows or hills giving easy gradients for short lengths. If the longitudinal section of a road is such that the load a horse may draw on the level can be taken over the steepest incline on the road without more than doubling the tractive force, the cost of cartage is not increased to any appreciable extent by those grades.

A draught horse working ten hours a day on a level metalled road with smooth surface can haul a load of 4 tons (Table II.) by the exertion of a tractive force of 160 lbs. On a 1 in 50 gradient very nearly the same load can be hauled if the pull is doubled. It may, therefore, be assumed that the introduction of inclines up to 1 in 50, four or five chains long, in an otherwise nearly level, well-maintained, metalled road will not restrict the loading, and that the cost of haulage will not be sensibly increased thereby. Investigations on similar lines for muddy earth roads show that the gradient may be about 1 in 20 for short stretches without raising the cost of haulage. When the inclinations are so steep, or so long, as to compel a reduction in the working time of a horse, or in the load that it could otherwise draw, the cost of haulage is increased. This increase will depend (1) on the amount of reduction in weight of loading, and (2) on the percentage of decrease in the number of trips made. From these elements the relative costs per ton-mile on the level and on the grade can be ascertained. The difference multiplied by the number of ton-miles per year will give the annual loss which, capitalised at, say, 6 per cent., represents the sum of money that may be profitably borrowed to eliminate the objectionable gradients.

38. The Ruling Gradient.—The maximum gradient desirable varies with the class of traffic, the hardness and smoothness of the road surface, and the costs of construction and maintenance. It is obvious, therefore, that no fixed ruling gradient can be applicable to all conditions. The ruling gradient should always be considered both as an ascent and a descent. As regards descent, it is principally a question of safety. A grade 1 in 20 is about the steepest that a horse drawing a light vehicle can trot down on a hard smooth road without brakes; 1 in 25 is as steep as should be admitted where vehicles such as coaches, well braked, are to be driven downhill at a trot; 1 in 10 is steep for a descent on a mountain road, but gradients of even 1 in 6 may be negotiated at a slow pace with strong brakes and great care. As regards fast traffic we are principally concerned with the effect of descents in fixing the ruling gradient; where the bulk of the traffic is heavy the effect on uphill haulage should govern the ruling gradient. When deciding upon it for a particular road the engineer should be guided by economic considerations, instead of merely adopting some arbitrary maximum at random, or because it has been found suitable elsewhere. It is difficult to arrive at a conclusion as to the relative merits of various grades that may be adopted as maxima, but there must be some criterion, and that undoubtedly is the financial aspect. Take for example the case for alternative routes for a metalled road from a small township to a railway station, one being 1¾ miles long, with a ruling gradient of 1 in 14; the other 2¾ miles long, with a gradient 1 in 21. The cost of the road works and land compensation is £400 per mile by either route, and the annual maintenance charges are estimated at £40 and £35 per mile respectively; 4000 tons of produce are to be carted annually uphill along the road, and there will also be a certain amount of light traffic, which, for the purposes of comparison, may be neglected. The rate of travel of the heavy traffic, allowing for short rests, may be taken as 2 miles per hour on the first-mentioned route, and 2¼ on the latter. Allowing for loss of travelling time in loading and unloading, the number of round trips that would be made per day of ten hours by either route would not exceed three. If the value of a team of six horses, wagon, and driver is as low as 15s. per day to a farmer, then each trip to and from the station costs 5s.; if teamsters are employed their charge will be at least 30s. per day. On a 1 in 14 grade metalled road in good order six horses cannot haul more than 1¾ tons when working every day, whereas on a grade of 1 in 21, 3½ tons gross load can be taken (see Table II.). The number of trips to be made per annum for the transport of 4000 tons will be respectively about 4000 and 1600, allowing ¾ ton tare with the small load and 1 ton where full loads are taken. Then we have the comparative estimates as under:—

1 in 14 grade—	
4000 trips per annum at 5s.	£1000
Interest and sinking fund, say, 6 per cent. on £700, cost of 1¾ miles	42
Maintenance, 1¾ miles at £40	70
	£1112
1 in 21 grade—	
1600 trips per annum at 5s.	£400
Interest, &c., 6 per cent. on £1100, cost of 2¾ miles	66
Maintenance, 2¾ miles at £35	96
	£562

Although the difference may appear to be large, the figures are within the truth, and illustrate forcibly the great losses involved by heavy gradients. In every case it must be remembered that, even with the most skilful location, easy gradients usually result in increased first cost owing to the greater length required; conversely, if the length is curtailed the grades must suffer. In cases where the traffic is light and unimportant, it may be found that the best policy is to keep the length and cost of the road down by adopting a steeper ruling gradient than would be otherwise desirable. In practice, when, owing to the natural configuration of the ground, the facilities for lengthening out are unfavourable, there is no choice in the matter of what would be a suitable ruling gradient. Very often, indeed, it is a case of a very steep road or none at all. The subject will be further discussed in § 46. In the above and all other similar comparisons throughout this work the actual figures must not be taken as representing average results, but must rather be regarded as illustrative of the methods by which one may determine the economy or extravagance of any particular courses of action. In the case just cited the roads would be very cheap ones, but if the first cost and maintenance were doubled in each case, a saving of £500 per annum would still appear.

39. **Maximum Gradients in Cities and Towns.**—The maximum or ruling gradient permissible on town roads depends, as before, upon the class and volume of traffic and upon the condition of the road surface. Longitudinal slopes which in a mountain road would be regarded as easy would be classed as steep in a city street. Whenever possible streets in cities and towns should not be steeper than 1 in 25. It is not always practicable to keep within this limit, and very much steeper lengths are frequently to be found. The following table gives the grades of a few city and suburban streets in daily use:—

TABLE VII.

City or Town.	State.	Street.	Gradient.	Length.
Sydney	N.S.W.	King-street	1 in 9	670 feet
Melbourne	Vic.	Collins-street	1 „ 14	660 „
Malvern	„	Glenferrie-road	1 „ 14	1500 „
Auckland	N.Z.	Parnell Rise	1 „ 7.8	726 „
„	„	Wellesley-st. W.	1 „ 11.9	1056 „
„	„	College Hill	1 „ 11.9	1550 „

There are so many vested interests affected by any alterations that it is almost impossible to regrade such streets to any considerable extent when once constructed. It is, moreover, illegal for any municipality to raise or lower the levels of a road to the detriment of abutting owners without payment of adequate compensation. See § 162, Chapter IX.

40. **Topographical Features.**—At first sight the undulations of the earth's surface seem to be entirely without system. Closer examination will prove that this is not so, and that a country is nearly always intersected by well-defined drainage lines. A notable exception to this general rule is found in the aeolian, or wind-blown, Mallee country, also in the newer basalt, which is irregular in its contours. The character of the streams depends on the rainfall, the presence or absence of forests, the physical features, and the geological formation. After the drainage lines the leading topographical features are the ranges and hills. Main ranges form the watersheds between the principal catchments. The top of a range may be wide and comparatively flat, constituting a tableland; or it may be narrow and sharp-crested, forming what is called a "razorback." Jutting out from a main range we find spurs or minor ranges sloping off towards the flatter ground below. Gullies are found between the spurs, and at their heads there are usually low places in the main range called gaps, passes, or saddles. Spurs fall away from a range at more or less steep inclinations, mostly between the saddles. As a general rule the slopes on one side of the range are steeper than those on the other, and in most cases the slope of a hill is flattest near its foot.

41. **Examination of the Country.**—Before the reconnaissance is undertaken every available map of the district should be collected. In Australasia most of the feature maps available merely show the hills by hachures or brush shading, with the relative elevations of but few points. Such maps are extremely useful in enabling a general idea to be formed of the configuration, but cannot be compared with complete topographical maps, on which the contours, referred to sea level, have been recorded. With the latter at hand, the general location can often be decided upon in the office, and much time saved. The absence of topographical survey maps of Australasia is much to be deplored, and until this important

work is done the engineer will as a rule have to compile his own feature maps, largely from actual surveys. Preliminary personal examinations should not merely be of lines, but of the whole district, and it may be made on horseback or on foot. A sketch map should be commenced, and extended as the reconnaissance proceeds, the framework being based on parish or other trustworthy plans. All ridges, spurs, gullies, saddles, buildings, &c., should be recorded. The features are best shown by hachures, as on preliminary examination the data are too sketchy for the compilation of contour maps, but steep and high hills should be distinguished graphically from low ones with easy slopes. The various soils and geological formations should be noted, as well as the strikes and dips of the strata. Very often there is a considerable difference between the soil on opposite sides of a range or spur, owing to the weather side being more denuded by exposure to rains and wind. The nature of the soils and rocks should influence largely the location when, on alternative routes, other conditions are about equal. Expensive cutting in hard rock should be avoided provided a solid rock bed and sufficient hard stone for metalling could be secured in softer ground. Bearing in mind that cartage of stone is expensive, and adds largely to the cost of construction, the engineer should, other things being equal, locate the road near suitable quarries or gravel pits. The amount of clearing, and the quality of the timber and stone available, should be noted, as both are sure to be required in construction. Note also the direction of flow of all streams, and ascertain as nearly as possible the maximum discharge of each and its flood level. Fords and bridge sites should be looked for and recorded. Beware of ocular illusions that may convey false impressions, and take nothing for granted without investigation. Hills always appear steeper when viewed from a distance; country covered with fallen timber, rocks, &c., generally appears more difficult than it really is, and there are so many ways in which one may be deceived that it is clearly not safe to trust to the eye alone. The most useful instruments for reconnaissance are the aneroid barometer, the clinometer, and the prismatic compass. Distances may be paced or even estimated by the approximately known speed of travel, whether on horseback or on foot. Where wheeled traffic is practicable, distances can be ascertained almost exactly by odometer or even by counting the revolutions of a wheel; this latter method, however, usually sends the counter to sleep. For the determination of slopes the clinometer is a specially handy instrument, but care must be taken to keep it in good adjustment. Formerly, clinometers could be obtained in small sizes only; nowadays they are made larger and with longer tubes, whereby the base is increased and the accuracy of the observations much improved. As the larger-sized instruments are still quite handy and portable, they are much better than the smaller ones. For converting vertical angle to gradient a table of natural cotangents gives the denominator of the grade by inspection, e.g., a slope of 3 deg. 30 min. means a gradient of 1 in 16.35.

42. Use of the Aneroid.—For the determination of the relative heights of ridges, saddles, junctions of streams, and leading features, no instrument is so portable and handy as a 2½-in. or 3-in. aneroid, "compensated" so as to give readings identical with those of a mercurial column. Aneroid barometers should be carried in leather cases slung from the shoulders, and should in all cases be read in a horizontal position after the glass face has been gently rapped with the knuckle or a pencil. Most aneroids are provided with an adjustable altitude scale divided so as to give direct readings in feet. The greatest caution should be exercised before accepting the results of barometric observations, even when two instruments are carried and duplicate readings are taken. As is well known, the atmospheric pressure varies greatly from hour to hour, so that all changes in readings must not be attributed to a change of elevation. To eliminate as far as possible the uncertainty that will arise on this account, it is advisable to arrange for readings at frequent intervals at some central station, so that fluctuations during the day may be ascertained and allowed for. If the use of a barograph, or, say, hourly readings, cannot be arranged for, it will be necessary to return to a station of a known height at the close of each day in order that the variation can be roughly ascertained, and corrections made on the assumption that the change has been uniform during the day. It is no uncommon experience to find the reading of the height of the initial station 200 ft. out on return after a day's exploration. Although accurate enough for approximate work the readings of the altitude scale cannot be depended upon for very close results, nor is it intended by the makers that they should. Atmospheric temperature enters largely into the calculation of barometric heights, and to ignore the correction on this account is unwise when fairly close results are desired. Altitude scales are usually graduated so as to give true differences of level when the mean of the atmospheric temperature at upper and lower stations is 50 deg. F. Table 8, from the report of the United States Coast and Geodetic Survey, 1881, shows the coefficient by which the difference in level as indicated by the scale must be multiplied in order to ascertain the true differences of level.

TABLE VIII.

CORRECTION COEFFICIENTS FOR TEMPERATURE AND AVERAGE HUMIDITY.

t = shade temperature of air at lower station.
t' = „ „ „ upper „

t + t'.	COEFFICIENT.	t + t'.	COEFFICIENT.
Degrees F.		Degrees F.	
50	0.9514	125	1.0315
55	0.9567	130	1.0368
60	0.9620	135	1.0420
65	0.9674	140	1.0472
70	0.9727	145	1.0524
75	0.9780	150	1.0575
80	0.9834	155	1.0626
85	0.9888	160	1.0677
90	0.9942	165	1.0728
95	0.9996	170	1.0779
100	1.0049	175	1.0829
105	1.0102	180	1.0879
110	1.0156		
115	1.0209		
120	1.0262		

EXAMPLE—

Reading of altitude scale at lower station, 185 ft.; temp. of air, 90°.
„ „ „ upper „ 1345 „ „ 60°.

Difference of readings .. 1160 „

t + t' = 150°. Coefficient from the above table = 1.0575.

So the difference of level is 1227 ft., and the error that would result from neglect of the temperature correction is 67 ft.

Aneroids are generally sluggish in their action, and do not work well when carried quickly up or down steep hills unless ample time is afterwards allowed for the instrument to adjust itself to the altered pressure. Better results, therefore, can be expected when the ascent or descent is gradual. The heights of important points should be observed on as many occasions as possible, so that the mean of a number of readings may be adopted. If the reconnaissance has been skilfully made there will be no difficulty in selecting two, or at most three, routes as worthy of trial survey.

43. Valley Roads.—Frequently the best cultivation land is found along the valleys, and if so the bulk of the population will be found there, rather than on the hills. When this is so the engineer must lay out the main roads along the valleys and provide means of communication between them by way of the most favourable saddles in the intervening hills. In the case of a road along a comparatively narrow valley the best situation will usually be on the margin of the flat. Provided that the ground is firm and above flood level, it is inadvisable to leave the flat, and undertake an expensive road in sidelong cutting along the base of the adjacent hill. When a valley road is decided upon its line should follow the flat ground, and attempts should not be made to shorten the length by cutting off bends as by route **A, B, C,** Fig 2, when an almost level grade could be obtained by way of **A, D, C.** The error illustrated is a common one.

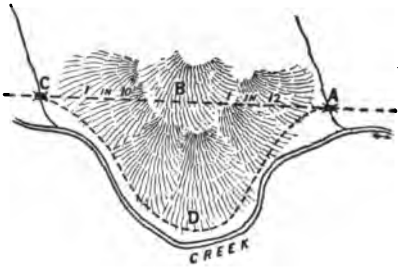


Fig. 2.
Showing Incorrect Location A B C.

Roads traversing sand hills are best kept as far as possible in or near the hollows rather than on the ridges, where they would be subject to the full violence of wind storms.

44. Roads in Undulating and Mountainous Country.—Generally it is necessary to extend a main valley road across the main watershed. Streams become steeper as one proceeds upwards until at their heads they are often precipitous. It is essential, therefore, that the road should not run too far up the valley, but should begin at the proper point to ascend in side cutting to the lowest saddle (see § 49). When the route lies across the drainage lines, as in the case of road parallel to the sea shore, one of two courses is open. Either the hills may be cut down and the hollows filled, or the road may be continued on the hillsides, easy gradients being secured by an increase of length. In rolling country a combination of the two is desirable, but in mountainous districts it is generally best to adopt the second course, by rounding off sharp curves, by filling gullies, and by cutting through the points of spurs, where, to avoid collisions between ascending and descending vehicles, the formation, even if narrow elsewhere, should be widened. The cost of bridges and culverts will largely influence the choice of routes, which should be considered with special reference to the principles laid down in §§ 14 to 17.

45. River and Creek Crossings.—The selection of river crossings is a most important point in the location of a main road. Streams should, where possible, be crossed nearly at right angles to their line of flow, as bridges and embankments on the skew are longer and more costly than those on the square. Approaches to bridges across wide flats liable to submergence should be avoided where possible, so that costly embankments with ample waterway for flood discharge may not have to be provided. In such cases the engineer is tempted to save money by omitting bridge openings, and so gets into trouble by causing flooding. When a valley is bounded by steep spurs running down close to the stream, the difficulty lies not so much in the actual bridge site as in the arrangement of the approaches. In such places it is only by the greatest care that sharp turns and dangerous grades can be avoided.

Fig. 3 shows a judicious choice of a bridge site with approaches contouring round the spurs.

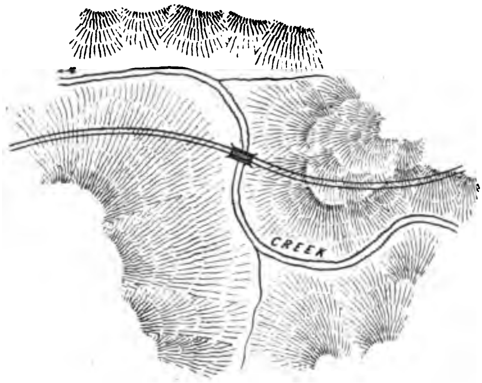
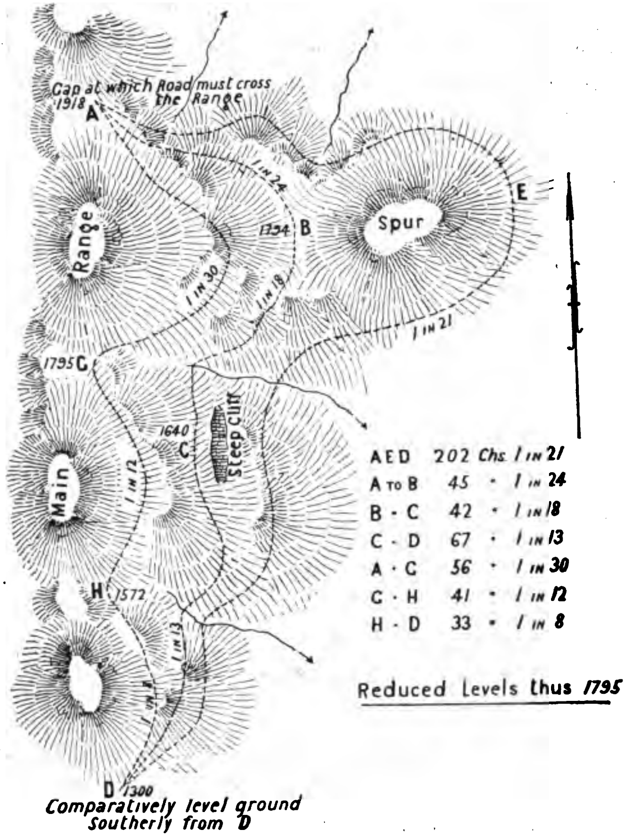


Fig. 3.

Bridges and culverts, always a heavy item in construction costs, should be avoided whenever possible without undue lengthening of the route. The cost of one bridge of moderate span may exceed that of a mile or more of road. Economy of structure design is considered in Chapter II.

46. Deciding on the Grades.—Having ascertained by aneroid the heights of the leading points, and knowing pretty closely how the contours run, the approximate line of the road can be sketched and the gradients ascertained roughly by dividing the length by the rise or fall. The ruling gradient can be decided on the considerations given in § 38. On a much-used mountan road 1 in 16 is as steep as is desirable; on sharper inclinations horses cannot conveniently trot down hill even with light buggies, and much time is lost in consequence. In mountainous country the ruling gradient may have to be made as steep as 1 in 10, but this should be regarded as the limit, unless in very exceptional cases. Fig. 4 shows alternative lines of road between points **A** and **D**. The levels shown have been ascertained by aneroid observations. The route **A E D** is on the comparatively easy gradient of 1 in 21, but is 202 chains long. **B** is a saddle in the spur, and by grading from **A** to **B** a grade of 1 in 24 is obtained. Between **B** and **D** a uniform grade would be about 1 in 15, but owing to a steep cliff at **C** it is found necessary to adopt slopes of 1 in 18 and 1 in 13. This example shows that without great outlay uniform gradients cannot be secured on all occasions. To determine which of the routes **A B C D** and

A E D is the more economical, estimate the traffic and cost of haulage, cost per mile, &c., and work out the financial result on the lines laid down in Chapter II., remembering that in this particular example the ruling gradients are 1 in 13 and 1 in 21. Route **A G H D** is given as an example of common, but very faulty, location, the road, in this case without any good reason, being graded between saddles instead of between terminal points **A** and **D**. In certain places this grading between saddles may be justified in order to render the road useful as a main outlet for properties on both sides of the range.



AED	202 Chs.	1 in 21
A to B	45 "	1 in 24
B - C	42 "	1 in 18
C - D	67 "	1 in 13
A - C	56 "	1 in 30
C - H	41 "	1 in 12
H - D	33 "	1 in 8

Fig. 4.

Showing Difficulties in the Location of Roads.

Fig. 5 shows how a road was located by crossing the main gully at **C** and sidling round a spur to the favourable saddle **B**, after which the ascent to **A** was easily accomplished.

47. **Curves.**—The sharpest curve allowable on a mountain road depends on the width and grade of road, and on the class of traffic. For example, easy curves must be provided for the safety of fast traffic, also on roads used by long teams of bullocks or horses unless the polers or shafters are to do all the pulling on curves. It is desirable that the centre line radius should not be less than 50 ft. except in extreme cases where curves as sharp as 25 ft. radius are barely admissible. At points of spurs, as remarked above, the curves should be flattened and the road widened, so that there vehicles may keep their own sides and collisions be avoided. At the curves at heads of ravines and gullies vehicles meeting are for some distance intervisible, but this is not so at spur curves, hence the danger arising from narrow roads in the latter situations.

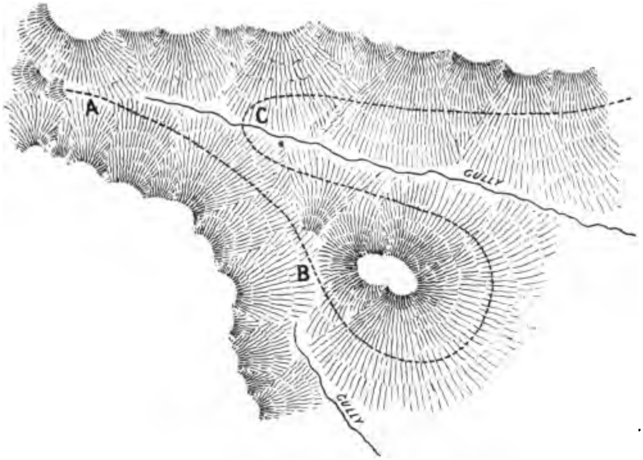


Fig. 5.

Location of a Road approaching Gap in a Main Range.

48. **Watering Places.**—On mountain roads provision should be made at intervals of, say, three miles for water supply, easily accessible to teams. In forest country the probability is that there will be abundance from natural streams.

In their absence water can generally be conserved and laid on to troughs kept just full by ball valve taps. At watering places the road should for obvious reasons be level, or nearly so.

49. **Trial Survey.**—Having determined the gradients as nearly as possible from the aneroid readings and the estimated length by scale, a trial line is run on the ground with the aid of a clinometer, or, better still, a small theodolite provided with a vertical circle. A large sized clinometer gives very good results, especially if supported by a stake whereby it can be held steadily at a uniform height and a sight taken to a cross arm or mark on another stake exactly the same height above ground. The procedure in running out the gradient is to set the clinometer over the initial peg and to wave the forward rod laterally until by trial and error the required vertical angle between the clinometer and the cross arm is secured. A peg is driven level with the surface at the point so found, the clinometer is moved forward to it, and the process repeated from station to station. The intervals between

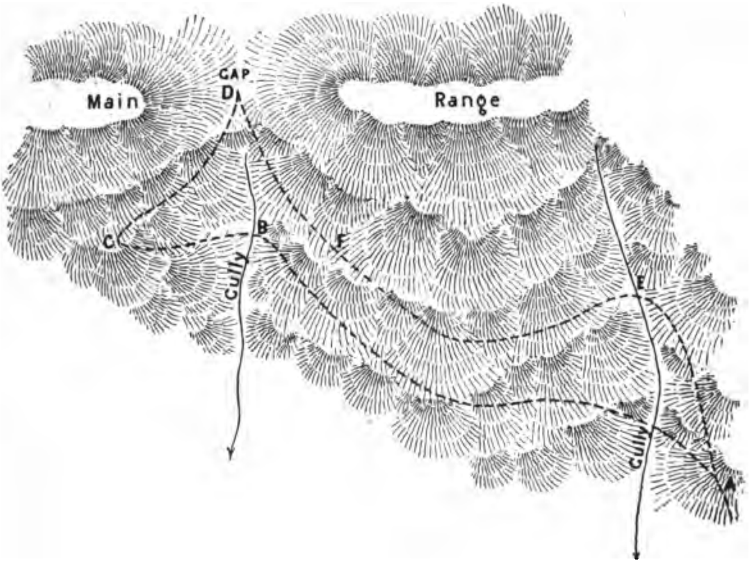


Fig. 6.

Showing Correct and Faulty Location.

stations are immaterial so long as the ground is regular, and they need not be measured at this stage unless the length is desired, either to facilitate the revision of the grade or to give data for an estimate of cost. Stakes are driven at each peg so that the general alignment can be seen.

When grading a road that must run through a gap or saddle, or from any fixed point, such as **C** to **D** (Fig. 6), less rigidly fixed, it is necessary to grade down hill. In Fig. 6 a road was run uphill from **A** with the intention of passing through the gap **D**. When **B** was reached that point was found much too low, and to reach the gap lengthening out by way of **B C D** was clearly necessary. This introduced at **C** a most awkward zig-zag or dangerous turn on the steep slope of the range. The proper course would have been to run downwards from **D**, lengthening out by way of **D F E A.**

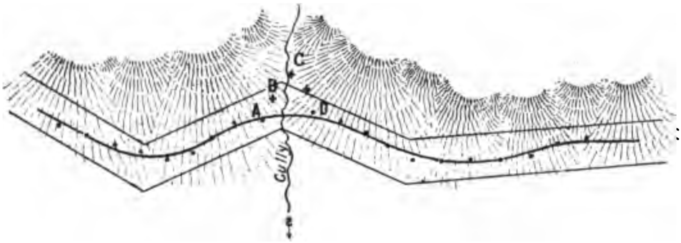


Fig. 7.

Showing Method of Grading.

When grading between two fixed points such as **A** and **B** or **B** and **C**, Fig. 6, the trial line may be run either up or down as is most convenient. In Fig. 7 the positions of the grade stations are shown by black dots. When a gully is met, instead of continuing the grade line as by **A B C D**, introducing a very sharp curve at **C**, it is usual to run the road across the hollow between **A** and **D** in embankment. As the distance **A** to **D** is much the shorter, it follows that if **A B C D** is laid out on the ruling gradient, the length **A D** will be very much steeper. On the contrary, **A D** being curved, the tractive force required to haul a load will be increased by curve resistance, and the grade should be reduced below the maximum allowable on a straight or moderate curve; care must be taken to grade from **A** to **D** by an air line. Whenever possible the section on sharp curves should be kept level, or nearly so. On long slopes it is advisable to introduce level benches about one chain long, and about half a mile apart, at which teams may rest.

In specially difficult country where the slopes along the spurs are very steep it may be found necessary to introduce spirals, in which there may be two or four intersections involving overbridges or even short tunnels. In such cases a complete contour plan should be prepared, by means of which the location may be carefully thought out and full scope given to the ingenuity and resource of the engineer.

The trial line is run out on the assumed gradient to the first fixed point through which the road must run. Very often the first trial line will strike above or below the desired level, owing to the uncertainty in estimating the gradient. If the difference is trifling the grade line can be corrected by interpolation, but if over a few feet the trial line will have to be rerun in the light of the additional information as to levels and length. With care, the second trial should be quite near enough. Transverse slopes should be taken by vertical angle observations every few chains to enable designs and estimates of the cost of construction to be made.

50. Tacheometer for Trial Surveys.—When specially good location is desired, it will pay to run a tacheometer traverse and obtain accurately, and in detail, the topographical features on a strip certain to include the road. As is well known, the tacheometer fixes with great precision the bearing, distance, and difference of level between two points without the use of a tape. Any ordinary transit theodolite can be fitted with stadia wires at a cost of a few shillings, and, if the telescope is reasonably good, excellent results may be obtained.

51. Width of Mountain Roads.—Road reservations are best defined by a series of straight lines, as shown in Fig. 7, in preference to mathematical curves, so difficult to reproduce in the event of the original survey marks becoming obliterated. The width of the reserve should be ample to allow plenty of room for cuttings, catchwater drains, and minor deviations that may be found advisable during construction. Usually a width of not less than 150 links should be reserved, and at difficult points it may be necessary to widen out still further.

52. **Final Survey.**—Having decided on the location within narrow limits, the line of road can be pegged and surveyed. The stakes, established by the grading trials, will be found to be somewhat irregular, as shown in Fig. 7. To avoid minor irregularities, the centre line is averaged up, as shown in the heavy line. In the case of a mountain road, the curves can often be worked in by eye, but in more important work they should be properly set out with transit and tape. The centre line should be pegged at convenient intervals, say about one chain, and levelled over with some one of the instruments mentioned above, so that longitudinal and cross sections may be plotted and the cuts and fills decided on. A traverse of the centre line, or offsets from the side lines, are required to fix the position of the formation. Cross sections should be taken frequently, trenches should be opened up for examination of the strata, and the positions of any buildings and fences should be recorded in the field notes.

CHAPTER IV.

EARTHWORK.

53. "Earthwork" as an engineering term comprises all the operations in loosening, removal and depositing of earth, soil, and rock. The scope of this chapter is to explain as briefly as possible the methods, implements and machinery employed in the construction of roads, and the cost of operation under Australasian conditions.

For purposes of reference and comparison, earths can be best approximately classified with regard to the difficulties with which they can be excavated. The following is adopted in this book:—

(a) Easy ground. This includes sand, loam, peat, and loose gravel, which can be dug out without picking, and which can be thrown readily from a shovel without clinging.

(b) Average ground. To this class belong clay, loam, sand, and gravel so compact as to require picking or ploughing before shovelling.

(c) Hard ground. This embraces very compact clays, marl, and tight gravel so hard as to be loosened with difficulty by picking, or such as requires at least four horses in a single-furrow plough.

Material that can only be dislodged by the use of gads or by blasting is considered rock, and is similarly classified into easy, average, and hard, according to its hardness.

Unless stated to the contrary, cost data given in this chapter refer to average earth (b), as defined above. Rock excavation and its cost are more particularly dealt with in Chapter VIII.

54. **Shrinkage.**—Earth when first thrown up by a shovel, without breaking down the clods or artificial consolidation of any sort, occupies more space than it did in place. Clean sand or gravel when first loosened swell about 15 per cent.*;

---

* "Cost Data," by H. P. Gillette, 1905, p. 73.

loam, loamy sand or gravel about 20 per cent.; dense clay and dense mixtures of gravel and clay, 33 per cent. to 50 per cent.; ordinarily, 35 per cent.; very dense clay swells about 50 per cent.

The extent of subsequent shrinkage depends on the means adopted to secure that consolidation. If settlement is the result of the action of rains and weather alone, the shrinkage will be slow, and the volume will at the end of a few years be about equal to the cutting from which it came. If, however, the embankment is put up in layers with carts or scoops, especially drag scoops, the shrinkage will be so great that the filling will occupy 5 to 10 per cent. less space than it did *in situ*, and the subsequent shrinkage will probably amoun to another 2 to 3 per cent. if scoops or road machines are used, but up to 10 per cent. may be expected in barrow and plank work. The height of embankment has but little effect on the percentage of shrinkage. Engineers frequently insist on banks being built well above grade line, an allowance of 1½ in. to 2 in. per foot of vertical height being commonly specified. Such a liberal allowance is advisable when the filling is hastily thrown up, but where care is taken to well consolidate by trafficking, watering, or rolling in construction an allowance of 3 per cent., or at most one inch per foot, is sufficient for any height of bank.

When solidity is essential, embankments are best made in the rainy season, as damp soils compact better than dry ones. A mixture of clay and gravel well sprinkled with water and well rolled in thin layers will shrink as much as 30 per cent. of its volume measured when first loosened. In ordinary construction with scoops the shrinkage at the end of three years is about as under:—

	Per Cent.
Loose vegetable soil	12 to 16
Loamy soils	10 to 14
Clay	10 to 12
Gravel and sand mixed	8 to 11
Gravel	8 to 9

When rock is broken up it increases in volume to the extent indicated in Chapter VIII. The increase amounts to from 35 to 50 per cent., according to the regularity of the sizes of the fragments, and the manner in which the stone is thrown into heaps. A reduction in the percentage of voids can always be expected after shaking down on a railway or road journey.

55. Side Slopes.—The batter allowable in road cuttings depends entirely on the nature of the soil, but is generally, for economical reasons, made as steep as is safe. It is usual to design the batter of cuttings and embankments as straight lines and to insist on their being built as such. The natural form of earth slopes is, however, curved; batters constructed to straight lines will gradually erode and slip until they assume a curved shape.

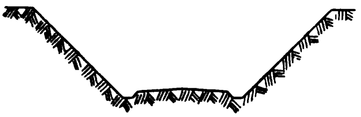


Fig. 8.

Cross Sections, as Usually Drawn.

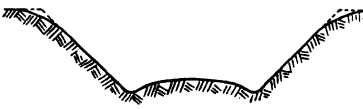


Fig. 9.

Cross Section, imitating Natural Conditions.

The cross section shown in Fig. 9 is rational and preferable to that shown in Fig. 8.

Ordinary earth cuttings will stand with slopes of 1 to 1, but 1½ to 1 is better, especially if the slope is a long one and gathers a quantity of water; 1¼ to 1 is often adopted as a compromise. Gravel generally requires 1½ to 1 batters; solid clay naturally dry will stand at 1 to 1, but when greasy may not be safe under 5 to 1, in which case it is sometimes cheaper to build retaining walls than to excavate on such a liberal scale. Sand is safe at 2 to 1 if planted with binding grasses or otherwise protected from erosion by surface waters.

Some engineers recommend steeper slopes, such as ½ to 1 in ordinary earth, for the reason that they consider it more economical to clear away the washings of denudation and occasional landslips than to incur extra expense in the provision of flatter slopes in the first instance. This policy is open to serious question, and is not generally adopted.

Solid rock will stand with slopes ranging between ¼ to 1 and vertical, or, when its stability is undoubted, may even overhang in awkward places, as shown in Figs. 135 and 137. When deciding on the side slope in road cuttings through rock, the dip of the strata must be fully considered. For example, in the case illustrated in Fig. 10, the strata dip as shown and the presence of veins of greasy clay render it liable to slip and flake off if the batter on the right-hand side is made unduly steep. **A B** can, under such conditions, be safely designed with a batter of ¼ to 1. The opposite slope must, however, be cut parallel to the dip, or a landslip, blocking the road, will probably result. This example is sufficient to illustrate the necessity for careful investigation, and shows how an unsymmetrical section is sometimes required.

Slopes of road embankments are generally designed at 1½ to 1, irrespective of the material, but in every case stability should be considered. The use of retaining walls in steep country is referred to in Chapter XVI.

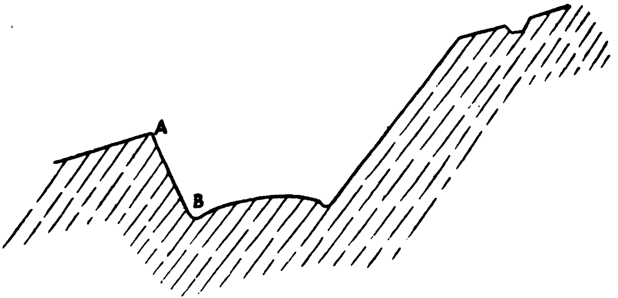


Fig. 10.

Showing how the Dip of the Strata influences Design.

56. Embankments.—Specifications covering high road embankments generally state that the earthwork is to be built up in layers. Such a requirement, though absolutely essential in reservoir construction, is unnecessary in ordinary road work, and specifications containing that provision are rarely, if ever, followed. It is advisable that the outer edges of high banks should be carried up somewhat in advance of the centre portion. This gives a general inclination inwards, and to some extent counteracts any tendency to outward slip. It is not to be inferred from what precedes that no importance is to be attached to the proper consolidation of road banks. If carelessly built they may give trouble for a long time, and if metalled swallow up a great deal of stone.

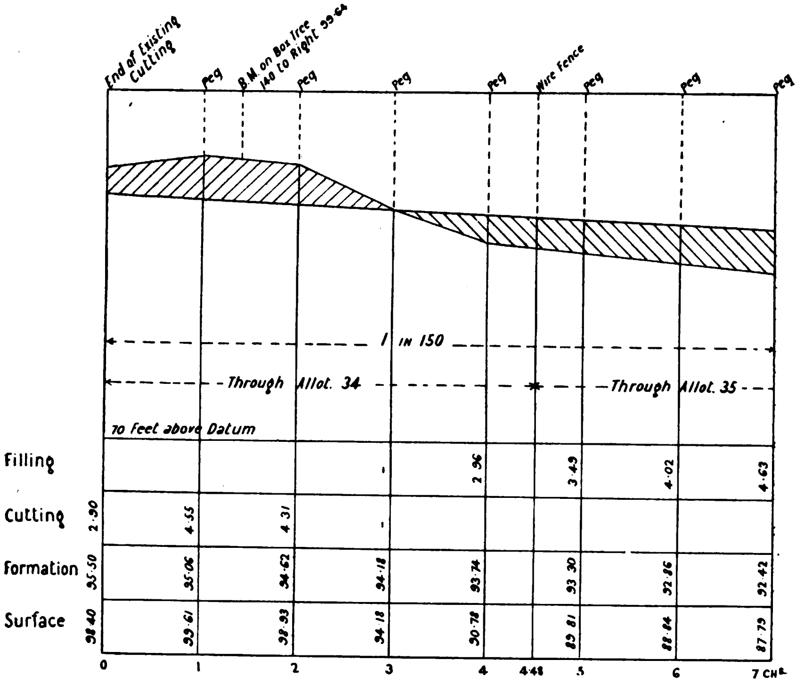
57. Road Banks in Swampy Ground.—It is generally better to divert a road round the margin of a spring than to attempt to drain such a place. There are, however, cases in which a road must be carried across a marsh. Even with deep side ditches it is very often impossible to drain swamps of considerable area, and the embankment must of necessity be placed on spewy ground. Filling cannot be taken from borrow pits if the ground is very swampy, and in such cases the work must be pushed out from dry ground. Compression of the foundation is certain to take place, and until the extent of the sinkage is known the quantity of filling required can only be approximated. An even distribution of the earth load during and after consolidation is most important, and is best secured by the laying down of a corduroy or brush foundation.

58. Balancing Earthwork.—In sidelong ground the grades are usually arranged so that the cross-sectional areas of cutting and filling are exactly balanced. It must always be remembered, however, that excavated material will, according to its nature, swell or diminish when placed in bank. In rock cuttings, for example, it must be remembered that each cubic yard of solid rock in cutting will produce at least 1 1-3 cubic yards of consolidated filling.

Where hills have to be cut down and depressions filled the spoil from the excavations has to be hauled forward. Fig. 11 shows typical longitudinal and cross sections of a short length of such a road, and illustrates how working drawings for this class of work are prepared on a distorted scale to show up the differences of level.

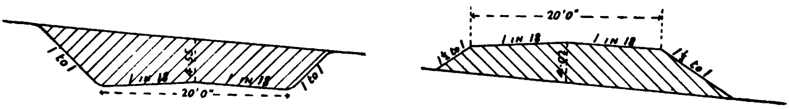
The most practical method of arriving at grades that give balanced earthworks is by trial and error. The proportions of cutting and filling can be very roughly approximated by inspection, though the relative areas on the longitudinal section between grade line and the surface are but a poor guide, since cubic content does not vary directly, but more nearly as the cube of the height.

The horizontal distance that material has to be transported is termed the "lead." The longer the lead the greater the cost, until at a certain distance it is cheaper to take material from



LONGITUDINAL SECTION

Scales { Horizontal 2 chains to an inch / Vertical 20 feet . . .



— At 1 ch. — — At 6 chs —

CROSS SECTIONS

Scale 20 feet to an inch

Fig. 11.

Typical Longitudinal and Cross Sections, showing Grading of a Road in Cutting and Filling.

borrow pits than to cart it forward. In contracts a common practice is to specify that the price for excavation includes the cost of transport up to a given distance, and that extra haulage will be paid for at the scheduled rate per chain for extra cartage. Disputes concerning the lead are common, and, generally speaking, the best course in road contracts where the quantities of excavation and embankment are definitely known is to specify that excavation is to be paid for at one uniform rate per cubic yard measured in cutting, irrespective of lead, and that the price is to include the placing of the material in embankment. The costs of clearing and rolling are also very often included in the price for excavation.

59. **Methods and Cost of Loosening.**—The cost of loosening depends largely on the method employed. Four horses in a single-furrow plough with driver and ploughman can loosen about 350 cubic yards of fairly stiff loam or gravel, or 250 cubic yards of fairly tough clay, in eight hours. If the hire of team and driver is 25s., and ploughman 7s., per day, the costs are 1 1-10d. and 1½d. respectively. It is important that a good type of plough should be chosen. The implement shown by Fig. 11a is a strong one, of steel, and very suitable for ordinary road work where the team consists of four horses.

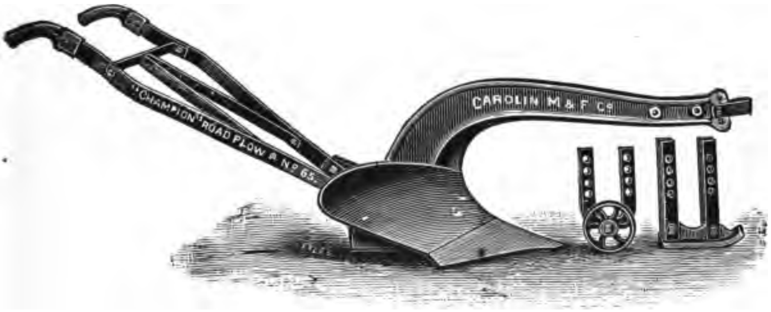

"CHAMPION" ROAD PLOW A No 65.
CAROLIN M & F Co

Fig. 11a.

Champion Road Plough.

For breaking up very hard surfaces such as macadamised roads, where a scarifier is not available, the plough shown in Fig. 11b is suitable. The team would consist of from six to twelve horses. Both these ploughs are made by the American Road Machine Company, of Pennsylvania, U.S.A.

The cost of loosening by pick is two to three times as great as by ploughing, but statistics usually combine the costs of picking with that of loading into drays or trucks.

The cost of pick and shovel work depends largely on the distance and height the earth has to be thrown. A good navvy can throw with a shovel about 11 ft. vertically, but the strain is very severe, and it pays best to place the benches about 6 ft. apart vertically, and to handle twice. For lifts higher than 12 to 14 ft. it generally pays best to use a windlass. The horizontal throw can be up to 12 ft., provided that there is no vertical lift, but the effort required to accomplish this result cannot be maintained for long. When the horizontal distance exceeds about 10 ft. it pays to handle twice; when over 20 ft. it is best to employ drays or barrows, as the circumstances of the case demand.

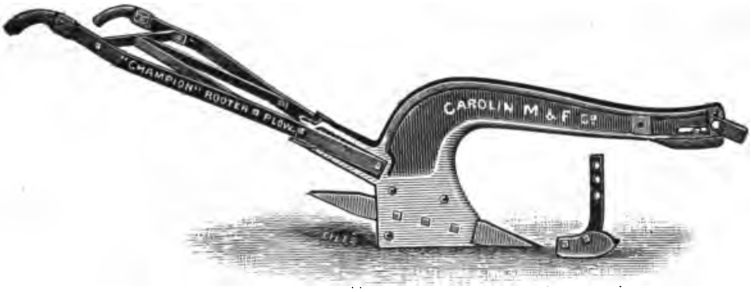


Fig. 11b.
Champion Pavement or Rooter Plough.

A strong man can dig out and load into drays 12 to 14 cubic yards of easy ground in eight hours, but only 10 to 12 cubic yards when on ploughed earth, where extra force is required to insert the shovel. The following figures represent the approximate cost of picking and shovelling into drays when the wages are 7s. per day for experienced navvies, or proportionately lower for less efficient labourers:—

	s.	d.
Sandy loam and light earth, easy ..	0	4
Average earth	0	7½
Tough clay	0	10½
Cemented gravel, up to	1	6

60. Barrow and Plank.—Wheelbarrow loads of about 1-14 cubic yard measured in the solid before loosening can be wheeled on fairly steep planks. An experienced navvy can load, wheel a distance of 50 ft., and dump about 9 cubic yards of average earth per day at a cost of about 9d. per cubic yard. Barrows should never be used without planks to wheel them on, or where the lead is greater than about 100 ft. The navvy generally estimates the lead by the number of planks 18 to 20 ft. long that he has to wheel over; for example, when the earth has to be transported 35 ft. it is termed a two-plank lead.

Barrow work is suited for the excavation of ditches, drains, foundations, &c., where the space is confined or where horses would bog, but is rarely economical in road works.

61. Cost of Carting and Dumping.—The load that can be taken in a single horse tip-dray depends largely on the condition of the surface traversed and the grades encountered. Under the most favourable conditions ¾-yd. loads can be taken, but over loose ground it is not safe to rely upon more than ½ yd. each trip, or even as low as 1-3 cubic yd. where the drays have to haul out of a cutting by steep roadways. By the employment of one or more leading horses the loads can, of course, be increased.

Assuming the average speed to be 200 ft. per minute, and that a trifle over four minutes are occupied each round trip in the backing into position, loading, dumping, &c., the number of round trips per day of eight hours on a lead of 500 ft. may be taken at fifty. If ½-yd. loads are taken, and the hire of horse, cart, and driver amounts to 11s. per day, the cost per cubic yd. for transporting this distance amounts to about 5¼d. Allowing an extra ¾d. for spreading, the total cost of excavating, carting, and spreading average earth a distance of 500 ft. is about 7½d. + 5¼d. + ¾d. = 1s. 1½d. per cubic yd. measured in cutting. It must be understood that the figures are not of general application, and that each case must be considered on its merits, with all local conditions taken into account.

62. Drag Scooping.—When the lead is short, steel drag scoops such as illustrated in Fig. 12 are very useful implements, which can be pulled when full up a 3 to 1 slope, and when partly full up 2 to 1. It is generally necessary to loosen the earth by ploughing before scooping. The scoop teams are arranged to travel in circles, one following the other. When estimating the output it must be remembered that the scoops are rarely filled to more than three-fourths their utmost capacity as given in manufacturer's catalogues.

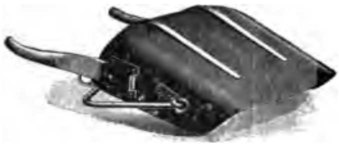


Fig. 12.
Drag Scoop.

When the lead is 75 ft., the distance to be travelled each trip may be set down at not less than 200 ft., which can be covered in just about a minute. Allowing for 1-3 minute loss of time each trip, and that loads of 1-6 cubic yd. can be taken, the quantity of average earth moved this distance per day may be taken at 60 cubic yds. With the wages of a team, driver, and scoopman at 22s., the cost per yard is 4½d., to which must be added the cost of loosening by ploughing at 1¼d. per cubic yd., and superintendence at ½d., making a total of 6¼d. per cubic yd. The cost for longer leads can be worked out on the same lines.

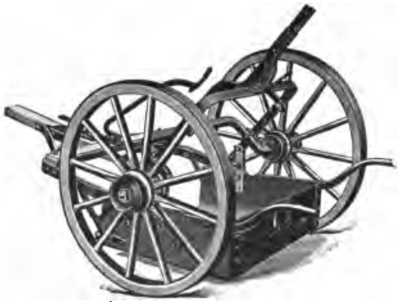


Fig. 13.
Wheel Scoop in Position for Filling.

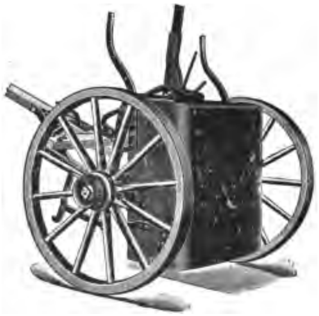


Fig. 14.
Wheel Scoop when Dumping.

63. **Wheeled Scoops.**—The Austin Standard wheeled scoop, made in four sizes, numbered 1, 2, 2½, and 3, and of listed capacity 9, 12, 14, and 16 cubic ft. respectively, is shown in Figs. 13 and 14. The average actual load of earth as measured in place before loosening is about three-fifths of the listed capacity.

Wheeled scoops are suited for much longer leads than are drag scoops, but they are not so easily filled in lumpy or stony ground. On long leads it pays to top up the load by shovelling in earth, after filling as far as possible in the ordinary way. With the larger sizes of scoop a snatch team must be employed to assist in filling. The cost by wheel scoops can be worked out on lines indicated in the last paragraph, and will show only a very slight saving for short leads. When the earth is to be transported some distance the saving over drag scoops is very great, and amounts to about 1d. per cubic yd. for every 100 ft. of lead beyond the first hundred.

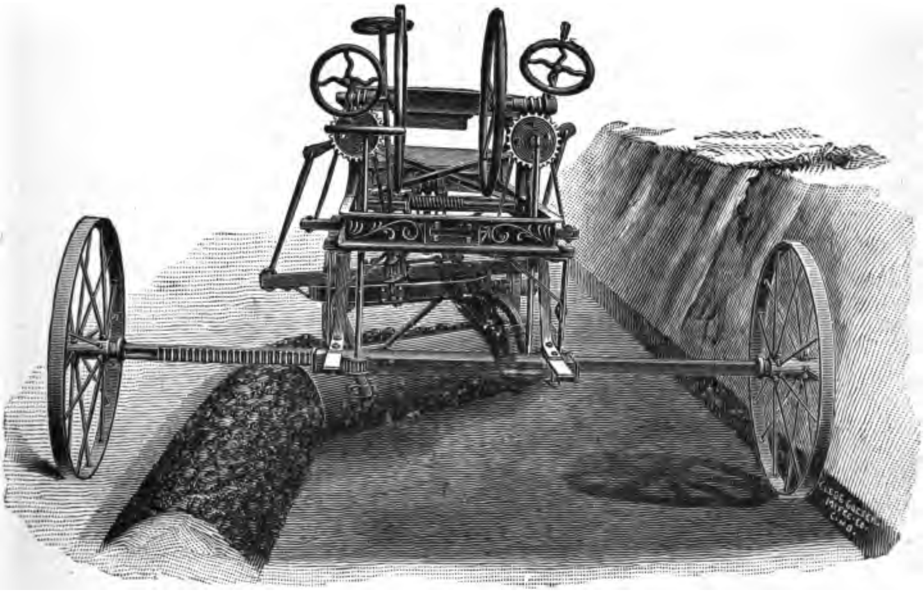


Fig. 15.

American Road Machine—Rear View.

64. Road Machines.—The American grader or road machine is a very useful implement, by which earth is scraped sideways from the watertable excavations to the centre of the road as shown in Fig. 15. This machine, which is made by the Acme Road Machinery Company, of Frankfort, N.Y., U.S.A., is hauled by a team of about six horses. Fig. 23 shows the implement in operation. The blade can be set at any desired elevation or angle to the direction of travel, and by a tilting device its pitch can be adjusted. Loosening by ploughing is generally required before scraping is commenced, claims to the contrary notwithstanding. When working in comparatively hard ground the top of the blade is tilted backward; in soft ground it is set almost vertical. The several makers adopt various devices for changing the relative positions of the rear wheels to the body of the machine and the blade. By the most common device the main frame of the machine is traversed along the axle in either direction, and automatically locks it at any desired point. Where the natural surface is fairly even, and free from large roots and stones, American road machines pack the earth evenly and solidly.

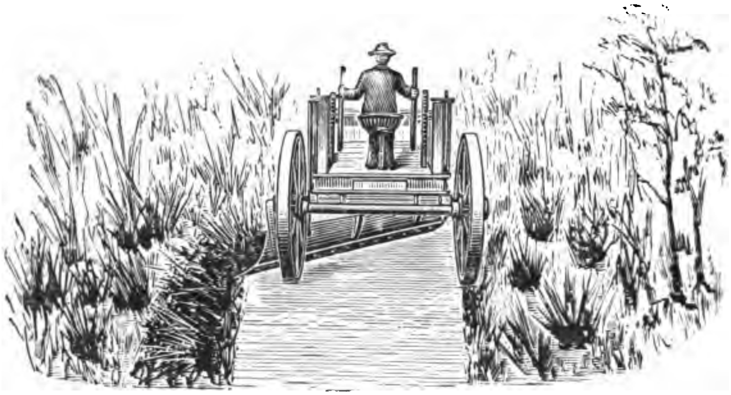


Fig. 15a.

These implements do not work well in loose, sandy ground; in pure sand, without some device to prevent the side slip of the rear wheels, they are of little service, and indeed in any case it will be found advantageous to shrink a band or tire of 1 in. square section on the ordinary tire to reduce the side slip and more effectively move the earth sideways.

Earthwork on roads of the cross section shown in Figs. 18, 19, 20, and 22 can be carried out for about 2½d. per cubic yd., inclusive of ploughing, but exclusive of loaming and rolling. Channels and drains up to about 21 in. deep can be cheaply and neatly excavated with these machines at a cost of from 2d. to 3d. per cubic yd. in the tertiary plains. For road-making in suitable alluvial ground there are no implements of their size and price (about £85) to equal them.

Fig. 15a shows a view of a road machine made by the American Road Machine Company, of Pennsylvania, U.S.A., in use as a fire break maker.

65. **Elevating Graders.**—The "New Era" grader has been successfully used in Australia for putting up embankments. The machine, which is drawn by about twelve horses or a traction engine, consists of a frame mounted on four wheels, to which is attached a plough and another frame carrying an elevating belt that delivers the excavated material at right angles to the direction of travel. The earth can be delivered anywhere between 14 and 22 ft. horizontally, and within a range of 9 ft. vertically. Five men are required to operate the machine. The cost of the machine described above is about £400 landed in Australasia. Smaller machines, capable of depositing the material up to 19 ft. horizontally and 6 ft. vertically, and requiring nine horses and four men, can be landed for about £300. When the ground is suitable, and free from roots and large stones, these machines are more economical than any other type. The first cost is high compared with road machines, but if sufficient work can be obtained the expense is well justified.

66. Example of Specification, for the Supply of Horses, Carts, &c.:—

SPECIFICATION referred to in foregoing Form of Tender, General Conditions and Contract Agreement, and to be observed in the supply of horses, drivers, carts, ploughs and scoops to be employed in forming roads, drains, or other works within the Shire of...

Horses.—All horses used in this contract must be heavy draughts, sound, strong, staunch, thoroughly broken to harness of all sorts, able to walk easily at the rate of two and a-half miles per hour when drawing load, well fed, and provided with strong, suitable and well-fitting harness, and properly shod, if so required by the engineer or his representative. They must be free from galls of any description, able to back well, and thoroughly fit for their work. Any horse that the engineer or his representative may consider unfit shall be at once put out of work and a fit animal substituted.

Drivers.—Every driver must be skilful, sober, and able-bodied, not less than 20 years old, and must perform his work to the satisfaction of the engineer or his representative, who may at any time call upon the contractor to dismiss any driver failing, in his opinion, to do his work properly. All drivers must follow the directions of the foreman in charge of the work they are at, and must take care not to waste time. Drivers of carts must work at the loading and unloading of same.

Ploughs.—Each team must be provided with a first-class approved heavy road plough, fitted with swingletrees and everything necessary for the proper performance of its work.

Scoops.—To each team of six horses one scoop containing at least half a cubic yard must be provided, and the team may be split up at the discretion of the foreman so as to work smaller scoops belonging to the Council when ploughing is going on, or it may be used in a road machine as under.

Road Machines.—The six-horse teams must be prepared whenever called on to work a road machine, the driver to take his directions from the man in charge of the implement. The machines are usually provided with swingle-trees, but in event of any deficiency the contractor must find his own.

Horses and Tip Carts.—The contractor must be prepared to find horses, carts, and drivers at the scheduled rates. Horses and drivers to be as described above, while tip carts are to be sound, strong, and serviceable, fitted with side-boards, capable of carrying 1½ yards of earth without loss, and suitable for carrying bluestone dust, dry sand, and thin mud. [If possible, tires 5 inches wide should be used, and this should be borne in mind and specified where practicable.]

General.—It is to be clearly understood that the foreman in charge is to have the power to arrange the work of the horses to what he considers to be the best advantage, each contractor selecting his own drivers, in accordance with specification above.

Rolling.—The teams may be used in rolling with the Shire roller, at the discretion of the foreman in charge.

Working Hours.—Each working day shall be of eight hours' duration, exclusive of time allowed for dinner and baiting of horses. Payment will be made at per whole-day, half-day, and quarter-day, any time less than two hours being considered a quarter, four hours one half-day. Time will be kept by the foreman in charge of the work. Work generally to commence at 8 a.m. No work will be done on Sundays or public holidays, except in cases of emergency, when it will be paid for on the basis of time-and-half rates. It is to be clearly understood that the Council is to have the full benefit of the services of the men and horses employed, and the working of either for the contractor's benefit outside the Council's working hours is strictly prohibited.

Wet Weather, &c.—The teams shall not work on any day when owing to wet weather or the wet state of the ground, the foreman in charge may consider that the work cannot be properly carried on, and only days actually worked on will be paid for.

Insurance.—The Council will not be responsible for any accident or injury to drivers, horses, carts, or implements, and the contractor must, at his own expense, effect any assurance he may consider necessary for his protection.

Liability for Damages.—The contractor shall be liable for any damage to any of the Council's property or plant caused by the operations of his drivers or horses and shall make good the same, reasonable use and wear excepted.

Shifting Camp.—Whenever the engineer or his representative may consider it necessary, the contractor must move his camp to be reasonably close to his work, half a day's pay being allowed for each shift.

Duration of Contract.—Contractors must be prepared to find teams for which they may tender for a period of...............months from date of acceptance, but the Council will not be bound to employ them for that time, though every effort will be made to arrange the work so as to be reasonably continuous. Contract may be extended at scheduled rates by mutual consent of the parties. No claim for compensation for failure to provide for continuous work will on any account be entertained.

Payments for satisfactory work will be made in full at intervals of about one month, and on completion of contract to the satisfaction of the engineer the deposit will be returned.

Tenders accompanied by a preliminary deposit of £.................... will be received at...up till noon of............ ...., and in the case of successful tenderers the amounts will be retained as guarantee deposits. Each tenderer must state clearly the number of horses, &c., he is prepared to supply.

Lowest or any tender not necessarily accepted.

CHAPTER V.

EARTH ROADS.

67. Included under the heading "Earth Roads" are those constructed of soil, which may be loam, clay, sand, or other soft material, without a crust or top, such as stone or gravel.

The bulk of the country roads of Australasia have been, and must for a long time continue to be, made of earth alone; for this reason we propose to deal pretty fully with this class of construction. A well-shaped earth road forms an excellent foundation for a gravel or metalled road, and its construction is, in many cases, preparatory to the more permanent improvement; for this reason alone, and apart from the considerations mentioned below, it is highly desirable that earth roads should be scientifically designed.

68. **Clearing.**—The first step in the construction of a new road is to clear the surface of scrub, stumps, trees, &c. The width of clearing necessary and desirable has been much discussed. An objection raised to the presence of trees on the sides of roads is that they shade the formation, and by retarding evaporation keep the surface wet and muddy. This objection is valid in wet districts or in places where the soil is naturally springy or damp, and in such situations it is advisable, if funds permit, to clear the full width of the reservation; at any rate, the clearing should be one chain in width. In hot districts shade is necessary for the comfort of travellers and animals, and generally the question of mud does not apply with such force. In such places it is well to leave growing trees on each side of the formation; on a one-chain country road clearing 40 ft. wide in the centre is enough. Roads through sandy country should be cleared as little as possible, for the reasons given in § 81. See § 82 for typical road-clearing specification.

69. **General Considerations.**—Generally speaking, it may be confidently asserted that in road making the worse the

material the more the care required in shape and manipulation; hence earth roads require most careful design. Water-tables or side ditches are required to carry off surface water and to intercept cross drainage, and the road should be in slight embankment, so that it may be dry. The cross section should be arranged so that the cutting will just balance the filling. In these days of labour-saving devices, road formation, like all other engineering works, should be designed so as to permit the use of scrapers or other modern machinery. It is ridiculous to blindly follow the methods of a period when the pick, shovel, and barrow were the vogue. In travelling through districts where there are a great many lengths of earth roads it is too often noticeable that there is great diversity of construction, and that practically each contractor makes the road that seems best to himself, treating the contract drawings as merely formal documents not requiring attention. This should not be so, and all contractors should be compelled to adhere closely to the plans and specification.

70. **Sub-Drainage.**—When the ground is naturally wet, and where the level of the water in the subsoil stands at less than about 3 ft. below the finished surface, a good road cannot be constructed without proper sub-drainage, because a formation goes to pieces if built on a plastic foundation. In districts with a low rainfall the level of saturation is generally many feet down; in such cases surface drainage alone needs to be considered. In other places, however, if a hole is sunk it will be found that water rises and stands within a few inches of the top. In such cases nothing short of a lowering of the water level in the neighbourhood of the formation will suffice, particularly if the ground be liable to become frozen to a depth of over 2 or 3 in. The greatest trouble from ground water may be expected in cuttings where the roadway is below the natural surface, and in roads running approximately along a contour on hill sides. Much can be done to lower the water by excavating side drains 3 or 4 ft. deep. Ditches of this depth are, however, unsightly, costly, dangerous unless well protected, and are in constant need of cleaning out. By far the most effective subsoil drain is constructed with porous agricultural drain pipes, as shown in Fig. 16; this form is superior to the flat stone drain shown in Fig. 17.

The pipes are generally 4 in. or 6 in., but should never be less than 3 in. in diameter, and should be laid about 3 or 4 ft. deep. One line of drain is generally sufficient if laid on the upper side of the road. Some authorities advise that they be placed under the centre of the formation, but the inevitable result of this is to weaken the foundation. The best position is under the flank or the watertable, but care must be taken not to place them where running surface water may erode the earth filling above them before it has set thoroughly hard, a process that takes years to complete. A fall of ½ in. per chain is the minimum allowable, but one of 2 in. per chain gives a better flow, and if the trench in which the pipes are laid is cut narrow on the bottom there is little fear of erosion with even much steeper grades, say up to 1 in 30. The trench would be evenly graded for the reception of the pipes, which are butted close against each other without joints of any sort. If they are covered with spalls or broken stone, and the filling is well rammed, there is no fear of the drain clogging unless tree roots are allowed to find their way to the pipes, especially if a layer of leafy boughs be laid between the stone and the filling. Agricultural drain pipes are generally made in lengths of 1 ft., and the average cost in Victoria is about as under at the potteries:—

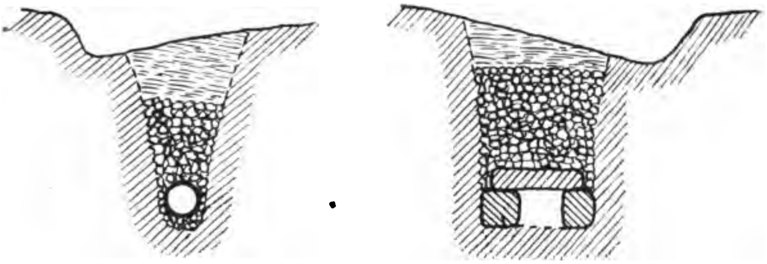


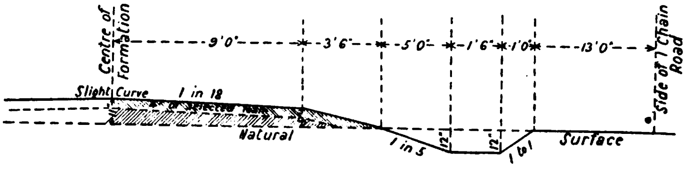
Fig. 16. **Fig. 17.**

Subsoil Drains, as Laid on Roads.

	PER HUNDRED.	
	s.	d.
2-in. internal diameter	6	0
3-in. „ „	10	0
4-in. „ „	15	0
6-in. „ „	35	0

See specificaion, § 179, Chaper IX.

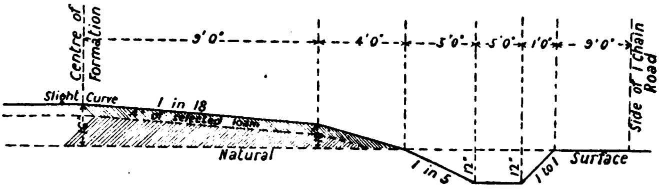
71. Cross Section.—For country roads the balanced cross sections shown in Figs. 18 and 19 give good results. In level country where no great quantity of surface water accumulates, Type 1 is sufficient; where, by reason of the contours of the ground a good deal of water flows or accumulates, Type 2 is better, and in certain cases a still higher formation may be necessary.



TYPE 1

Fig. 18.

Half Cross Section of Earth Road—No Scale.



TYPE 2

Fig. 19.

Half Cross Section of Earth Road—No Scale.

On wide roads in flat country the cross section Fig. 20 is considered by some to be an improvement, as it provides a track on either side of the formation between it and the water-tables for summer traffic.

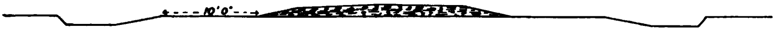


Fig. 20.

Typical Cross Section of Earth Road suited for Summer Traffic.—No Scale.

Fig. 21 illustrates a profile to which there are practical objections, summarised as under:—

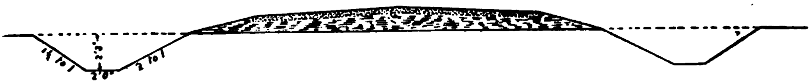


Fig. 21.

Undesirable Cross Section of Earth Road.—No Scale.

(a) The design precludes the effectual use of labour-saving machinery, both in construction and subsequent maintenance. Road machines cannot be economically employed in cuttings more than about 1 ft. 9 in. deep, and scoops will not take out beds under about 2 ft. 3 in. wide. Pick and shovel work is, therefore, unavoidable, and the cost per cubic yard increases in consequence.

(b) The watertables are unnecessarily deep; in ordinary cases effective drainage can be secured by side ditches about 2 ft. below the crown of the road. Deep drains are admissible only when the watertables are graded through rising ground, or in very swampy places where drainage of the subsoil is desired, and where the volume of water to be dealt with is too great to be discharged by underground drains.

(c) The whole of the dirt from the watertables is, as a rule, placed in the formation; over 70 cubic yards per chain, exclusive of loam, makes the crown unnecessarily high and the road dangerous.

(d) The excessive transverse slopes will cause the formation to gutter towards the watertables.

In the opinion of the authors the advantages to be derived from a radical departure from Types 1 and 2, designed for flat country, will not warrant any large increase in first cost.

For the reason that wet earth kneads into mud, surface drainage of earth roads is all important. Opinions differ as to the best transverse slopes. All agree that the centre should be higher than the sides, and the worse the material the greater the side slope necessary; thus an earth road requires more crown than a metalled one. Some consider that a circular arc gives the best cross section for the crowns, while others favour the ellipse, parabolic curve, or straight lines joined by a slight curve. Each form has its advantages, but the last mentioned is easy of construction, is as good as any for earth formations, and is recommended. The effect of too steep a side slope is to force the traffic into one track along the centre, this being the only part of the formation where vehicles can run fairly upright, and the result is that the road is worn hollow in the middle. It is more difficult to haul vehicles running on a steep side slope than on the level, because the weight is unevenly distributed on the wheels and axle friction is increased; then, again, when the vehicle is unduly tilted side slip damages the road, and mud and dust dropping from the rims fall clear of the wheels, and a general outward spreading of the formation results. On earth roads the transverse slope should never be steeper than 1 in 12, nor flatter than 1 in 24. On formations longitudinally nearly level, 1 in 18, as shown in Figs. 18 and 19, is very suitable. When the road is rising or falling sharply, the transverse slope should be greater than on flat ground, because the tendency should be for the water to drain to the watertables, and not longitudinally down the formation. A good test of the sufficiency of the width of a road, as well as of its shape, has been found to lie in the possibility or otherwise of two ordinary buggies being comfortably driven thereon, side by side, in the same direction. If they cannot be so driven the formation is too narrow, or the transverse slopes are too steep, and the traffic is pretty certain to be concentrated on one track.

72. **Watertables.**—The watertables are better wide and shallow than deep and narrow, as they are then easier to construct, besides being safer and cheaper to maintain. We have found that 12 in. is sufficient under ordinary conditions, and this depth should be exceeded only in cases where drainage requirements call for a greater one.

In the dry plains of Australia it has not been the practice to grade watertables where the ground is even and with a fairly uniform longitudinal fall. Where water is likely to lodge in the watertables and remain there for any considerable time grading is absolutely necessary, as will be obvious when it is remembered that 20 in. rain over each mile one chain wide represents about 3,630,000 gallons. The maximum allowable fall for watertables on sloping ground depends upon the soil and the quantity of water to be provided for. Clayey soils as a rule are more liable to erosion than sandy or loamy ones, in which a fall of 2 ft. per chain will often stand very well, provided that the water is not carried for a long distance. Much can be done in arresting erosion temporarily by the insertion of brush fascines at a very small cost. Where there is a large catchment area above the road, the water must be taken across it pretty frequently, or a large substantially-lined channel provided, so as to carry a considerable volume to the cross drainage works next below. Culverts and cross drainage works are fully discussed in Chapter XV.

73. **Construction.**—Earthworks can be carried out by some of the implements described in the last chapter, or by pick and shovel work, where the use of machinery is absolutely impracticable. Where the natural surface is fairly even, earth roads can be well and cheaply made by the American road machines, which, when properly used, pack the earth evenly and solidly. It is a great mistake to plough or disturb the natural surface under the formation, as is sometimes done; this only allows rain water to find its way into the subsoil, and to soften it, so that wheels sink deeper than they otherwise would.

The best season in which to construct earth roads depends upon the rainfall of the district. In dry climates they should be made at the end of winter or early in spring, when they will not be unduly muddy after completion, but will contain sufficient moisture to ensure a hard set before the dry weather sets in. In districts with a heavy rainfall, formations are best carried out in the dry season, usually the summer. In the coastal districts of Queensland, and in other places subject to tropical summer rains, the winter, generally dry and fine, would be chosen for roadmaking.

74. **Loaming.**—It will be noticed that in Types 1 and 2, Figs. 18 and 19, a central width of 18 ft. is "loamed" 4 in. deep. This loam is the best of the sandy soil to be found near the work, and which is observed to make a good natural road. Where all the ground to be moved is of a sandy nature, loaming is, of couse, superfluous. The types shown are specially designed for use in tertiary plains, where there is generally a depth of 6 in. of soil, more or less sandy, overlying tough clay, and where, in the depressions, the natural surface makes a bad road owing to the almost total absence of the usual coat of sandy loam.

75. **Channels on Roads.**—Irrigation channels should never be placed on roads under two chains in width, and not then

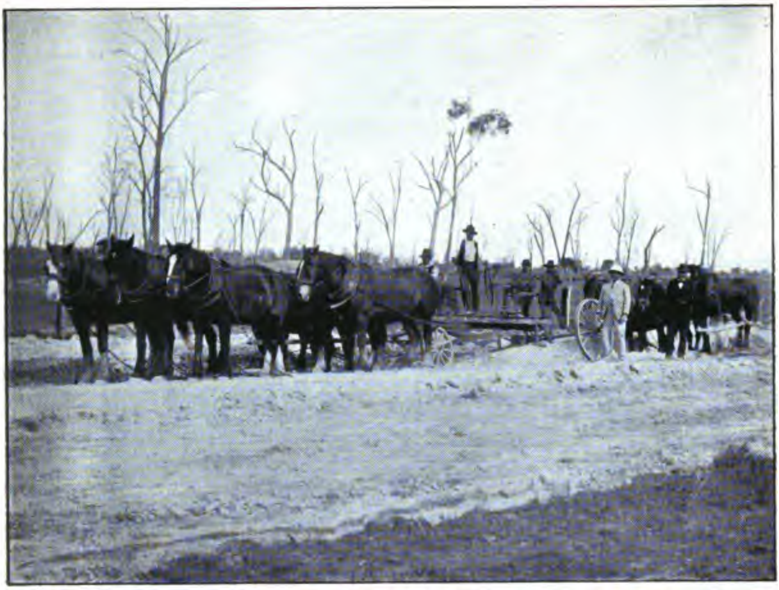


Fig. 23.
Road Formation and Channel in Course of Construction.

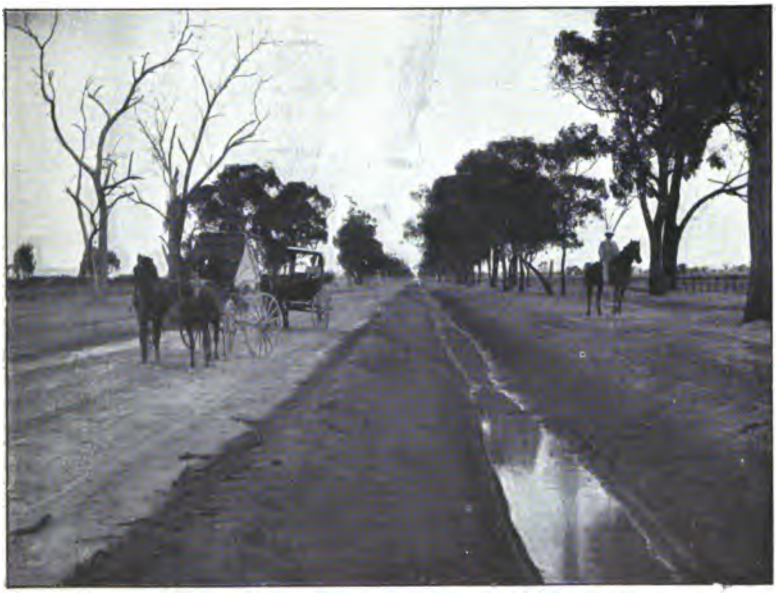


Fig. 24.
Road Formation and Channel Completed.

To face p. 83.

if it can be avoided. Except in the very best ground, there is always seepage from channels in which water is raised above natural surface level, and a waterlogged foundation is the result. In flat districts with scanty rainfall, small stock and domestic supply channels can, however, often be excavated on roads without any harm resulting. This can be done by enlarging one of the watertables, as shown in Fig. 22.

Care must, of course, be taken to properly grade the bed. The authors have had over a hundred miles of such combined channels and roads economically constructed in Northern Victoria, with very successful results. The excavation down to 1 ft. 9 in. deep, and the formation, was done with road machines; the bottoms of cuts over about 1 ft. 9 in. deep were taken out with scoops. Figs. 23 and 24 show a channel in course of construction and after completion respectively.

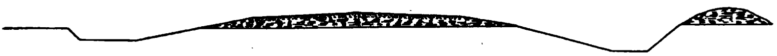


Fig. 22.

Showing Stock and Domestic Supply Channel combined with Road Formation.

76. **Water Breaks.**—Given sufficient crown, water will generally flow to the side ditches without washing out the surface. On very steep gradients, however, water breaks are sometimes necessary to divert surface water that would otherwise run down the wheel tracks that inevitably develop on earth roads in hilly country subjected to heavy traffic. As usually constructed, these water breaks consist of a narrow gutter diagonally across the road, with a corresponding mound below it; in this form they offer considerable obstruction to the passage of vehicles, and cause destructive jarrings to springs and axles. When absolutely necessary, they should be shallow, and at least 4 ft. wide, running nearly at right angles to the formation, and should preferably be paved.

77. **Reconstruction of Roads.**—Improvements to existing country roads, whether in earth formation or metal, may be effected in various ways:—

(1) By relocation with a view to the elimination of steep gradients, awkward stream crossings, or boggy ground, by deviating the road. For the various considerations affecting relocation see Chapter III.
(2) By regrading without alteration of the alignment. The work will consist of cutting down hills and filling hollows, so as to ease the gradients.
(3) By subsoil drainage works, such as are described in § 70, and specified in § 179.
(4) By re-formation.
(5) By improving the surface.

78. **Re-formation.**—An earth road that has been neglected for many years can only be put into good order by a general re-formation. It will probably be found very much out of shape, the crown having worn down, leaving the flanks as high or higher than the wheelway, with absolutely no provision for drainage unless it be along the formation. In flat country the watertables will be almost completely filled and useless as drains, while in undulating or hilly ground they may be dangerously eroded. The cleaning out and protection of drains should be attended to first, after which the road should be reshaped with ploughs and road machines or scoops to accord with an approved cross section. The improvement of the surface is discussed in the two succeeding paragraphs.

79. **Improvement of Clay Roads.**—In summer a clay road bakes hard and forms an excellent track, which, owing to the binding properties of the material, does not grind into dust so readily as lighter soils. Clay alone is, however, too soft and plastic to bear traffic in wet weather, and makes a very bad road, although thorough drainage of the subsoil and the preparation of a well-shaped surface from which water will run off quickly, goes some way towards improvement, allowing the crust to dry quickly after the rain ceases. It is hopeless to expect a permanent improvement by merely scraping a clay road into shape. What is wanted in all cases in addition to correct shape is the addition of gravel or metal, or a dressing of sand or sandy loam less plastic than the clay itself, and which the wheels of vehicles will not pick up in wet weather. Clay roads, which for years have been almost impassable

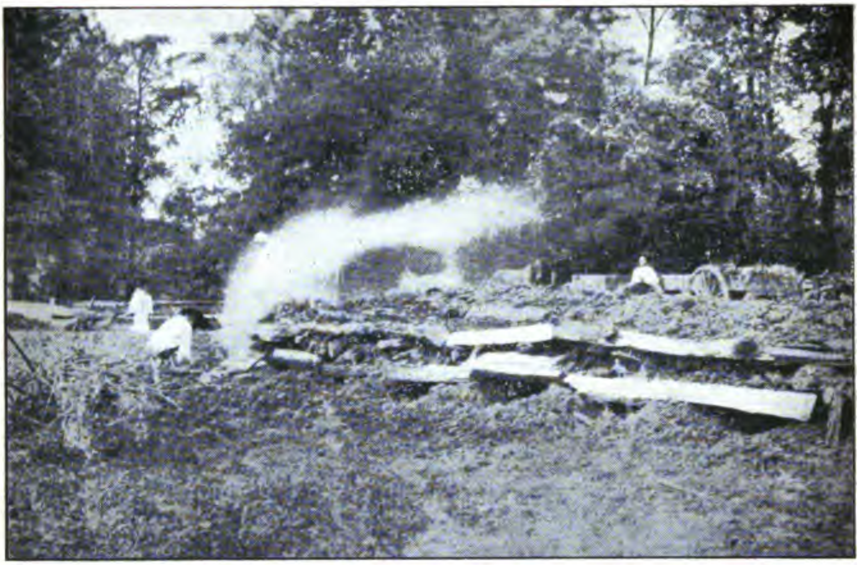


Fig. 25.
Burnt Clay Road.—Pile of Wood and Clay completed and Firing begun in one of the Flues.

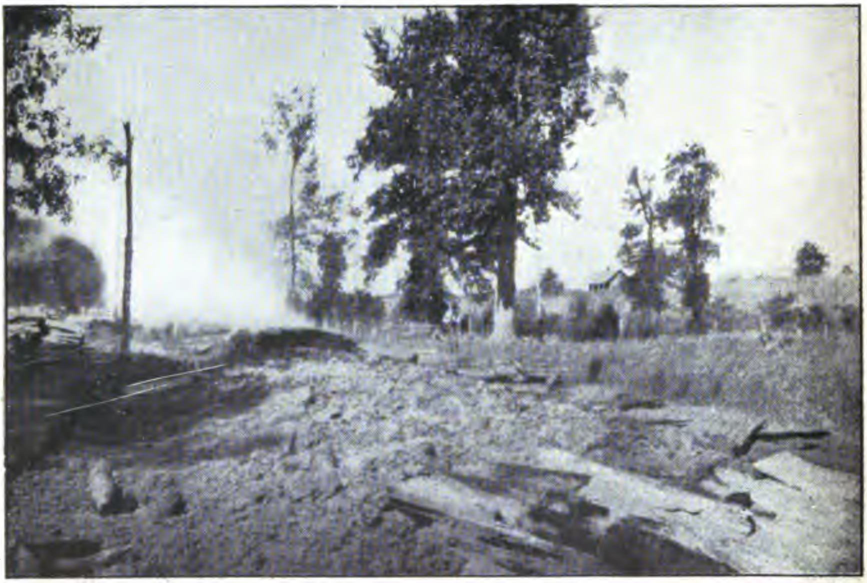


Fig. 26.
Burnt Clay Road.—One Section of Road burnt and a Second Section being fired.

To face p. 85.

during the rainy season, have been so changed by the addition of sandy loam that a vehicle may be driven over them at a trot on almost every day of the year. Where sand, sandy loam, or wood ashes are available they can be used on clayey formations with good effect, if applied in two or three layers of not more than 2 in. or so at a time, so as to allow of the added material being beaten into the clay gradually. The object sought is to secure a mixture of the clay and sand with just enough of the former to bind the particles of the latter. To ensure the mixture of the clay and sand, it is well to plough and scarify the surface before the latter is applied. Loosening of the clay surface is often omitted on the score of economy, with the result that possibly more than half of the sand is blown away before being beaten in by traffic. Coarse angular sand is the best for roadmaking purposes.

80. Burnt Clay Roads.—When sand and gravel, wherewith to neutralise the sticky character of the native material, cannot be obtained at reasonable cost, the sedimentary clay itself can be burnt and utilised, after cooling, in re-forming the surface. Clay, especially that containing a high percentage of organic or vegetable matter, cannot be burnt on a road to any great degree of hardness; it may, however, be so oxidised as to provide, after rolling, a porous non-plastic wearing coat.

The method of burnt clay construction described below is on the lines followed by the Office of Roads, U.S.A., Figs. 25 and 26 being reproduced from Bulletin No. 27. The clay on the line of formation, after being roughly formed, is ploughed deeply. Transverse trenches about 1 ft. deep and 18 in. wide are cut between the side ditches at intervals of about 5 ft. between centres, the excavated material being heaped up between them. A layer of 5-ft. logs is laid across the trenches, the ends resting on the ridges, so as to form a series of flues. Another layer of wood is laid irregularly across this floor, the spaces between the logs being filled with clods of clay loosely placed so as not to spoil the draught. A third layer of firewood is laid parallel to the first, the openings and cracks being filled with twigs, bark, &c. Finally, a top layer of clay, taken from the side ditches and at least 5 in. thick, is added and gently tamped. Coal slack, if available, can be substituted for the two upper layers of wood fuel, and mixed with the clay.

The wood in a group of, say, twenty flues is fired on the windward side, and the combustion regulated by banking the mouth of the flues where necessary. When burnt out the whole of the clay above the kiln, as well as that in the ridges between the transverse trenches, should be thoroughly calcined, forming, when levelled, a layer about a foot deep. This after crowning, preferably with a road machine, will compress under the roller to an average depth of about 8 in. One cord of firewood of average quality suffices for about 12 square yards of surface, while the total cost of labour amounts to about 6d. per square yard.

Burnt clay roads have been successfully constructed in the country lying to the south of the Koo-wee-rup Swamp, Victoria, and in other places. The cost, even when firewood is cheap, is not much short of £400 per mile for a strip 12 ft. wide. The result is satisfactory, but a plentiful supply of fuel is essential to anything like economy.

81. Improvement of Sandy Roads.—As is well known, sand, when confined, will support almost any weight, the objection to sand alone as a road material lying in the total absence therefrom of any binding or cementing qualities. Sandy roads are good only when damp, that is, when held together by what is called the "water bond." It is useless to form or crown sand roads, as they do not require drainage, and only dry the quicker for it. The growth of shade trees should be encouraged as much as possible, as these serve to keep the track damp, while leaves and twigs from the trees all tend to bind the sand together. Sand can be made hard and unyielding by filling the voids with finely-divided particles of material in the form of dust. Where gravelling or metalling is out of the question, nothing improves a sandy road so much as the addition of 6 in. or even 4 in. of gritty clay, which should be applied in layers of, say, 2 in., so that the finely-divided particles of clay may be mixed with the coarser sand as completely as possible. Ferruginous clays are the best, and pipe clays the worst, for road making, while clay added in lumps is useless until broken down. Loose straw, tan, or other refuse, such as that of sugar cane, spread to a depth of about 4 in., will in several days work into the sand and form a hard road, provided that the traffic is sufficiently constant to beat in the added material before it blows away or catches fire.

One of the greatest difficulties experienced in sandy country is in keeping the roads free from wind-blown sand. Much good can be done by planting hedges and wind-breaks of tea-tree or other suitable growth, and by retaining as much of the natural foliage as possible in the vicinity of the road. Great success has attended the planting of marram grass in Victoria and elsewhere, with the object of arresting the advance of sand hills that threatened to obliterate not only roads, but pasture and cultivation lands. The use of this valuable grass is certain to extend when its merits are more widely known and better appreciated.

82. Specifications for Earth Roads.—The following specimen specification and schedule are suitable for clearing to any width that may be desired, forming, loaming, and rolling a country road for a municipal council. On the preparation of contracts consult Chapter XVII.

TYPICAL SPECIFICATIONS.

CLEARING AND FORMATION OF ROADS.

For General Conditions, &c., see Chap. XVII.

For widths as scheduled for full clearing all living and dead trees and all stumps and saplings will be grubbed out to a depth of at least one foot, and all roots will be run to nine inches below the surface. All logs, scrub and debris, together with the grubbed timber, will be burnt off or removed, and all rocks and stones will be cleared away and disposed of so as not to interfere with traffic, as the engineer may direct.

All root and stump holes are to be properly filled in, an allowance of four inches per foot being made for subsidence.

The remainder, if any, of the width of the road will be cleared of all dead trees, logs and stumps, and of all saplings under six inches diameter three feet from the ground, grubbing as above, and removing and disposing of, as before, all scrub, rocks and debris.

The contractor must in all cases take all risk that may arise from the spread of fire.

The extent of the clearing required, full or partial, or both, for each length forming an item, will be stated in the schedule, and the price scheduled is to be at per chain forward for the completed work.

Injury to fences must be avoided as far as may be, and all unavoidable damage must be made good to the satisfaction of the engineer, at the expense of the contractor, who, to avoid being called on by landowners to repair damages not caused by the works of his contract, should draw the attention of the owners to any breaches or defects existing at the time of the commencement of the work. It is to be understood that the engineer will insist on the proper repair of all fences, and the making good of all damages of every kind caused by the clearing operations.

Branches and boughs overhanging the area to be either fully or partially cleared are to be removed for a height of fifteen feet above the ground.

No bench mark tree, or survey or level peg is on any account to be disturbed without permission from the engineer.

During his operations the contractor must at each end of each length, and at all cross roads, post notices in large type warning the public that the road is closed against traffic, and that they travel at their own risk, and he must, between sunset and sunrise, keep bright lights burning in the situations mentioned.

Sub-Drainage.—[See Chap. IX. for specimen specification clause.]

The Formation is to be in accordance with one of the types shown on attached drawing [see Figs 18 and 19] as may be scheduled, and great care must be taken to adhere closely to the cross sections, and to positions indicated on locality sketches or in schedule. Approaches with longitudinal slopes not steeper than 1 in 20 will be required at each end of each length of formation, and the cost of these will be considered as included in the scheduled price per chain for the work, but their lengths will not be included in the final measurement. Should it be found that sufficient banking material cannot be obtained from the watertables as drawn, they may be widened as approved by the engineer. Opposite approaches to properties, at cross roads, and wherever the engineer may consider necessary, blanks are to be left in the watertables or loam borrow pits mentioned below. In the construction of the banks the spoil resulting from the first ploughing will be used as far as practicable to form the middle twelve feet, the spoil from the second ploughing being used for the haunches. All large clods must be broken, and an allowance of 1½ inches per foot of height of bank made for subsidence.

Loam, of the best quality obtainable within 20 chains of the sites of the formations is to be spread 4 inches thick as per cross section, the quantity required per chain being 15 cubic yards for type 1. The loaming of the formations being of great importance, special care must be taken with this part of the work as to quality, quantity, and even spreading. Loam borrow pits are to be, unless otherwise ordered, not more than 8 feet wide, or 6 inches deep, and no part must be nearer to sides of road than 5 feet or further away than 13 feet. They must be neatly trimmed and cleared up on completion. The loam must not be left in heaps unspread on the formation, unless each length is properly protected by fencing and lighting at each end, and a practicable track elsewhere on the road is provided.

Rolling.—After the completion of the earthwork the whole is to be thoroughly rolled at least six traverses with the Shire or other approved roller, all depressions and inequalities being made up with good loam. If the shire roller is used it will be lent to the contractor on the understanding that he is to take it from whatever part of the Shire it may be in, complete his work, and convey the implement at once to............ ...., and make good at his own cost any damage that may occur to it, fair use and wear excepted.

Completion.—Should the work not be finished within the specified time, and should the ground not be in a fit state for rolling and dressing during the currency of the maintenance period, the contractor must put his work in order as above on the first suitable opportunity without extra charge. This proviso, however, is not to vitiate the Council's right to impose penalties for delay.

Culverts, when ordered, will be constructed in accordance with the detailed specification which will be supplied, and the formation will be modified to suit. Cost of excavation of foundations will be included in the price for the culvert.

Maintenance.—The work after completion must be maintained by the Contractor at his own expense in good order and condition for two months, or such further period as may be necessary in accordance with clause above.

SPECIMEN SCHEDULE.

No.	Quantities.		Description of Work.	Rate.	Amount.		
					£	s.	d.
1	40	chs.	Clearing road fully for 40 ft. wide in the centre, balance of width as specified, at per chain				
2	30	chs.	Formation of road as per Type No. 1, including approaches, loaming, rolling, &c., complete as specified, at per chain				
3	10	chs.	Formation of road as per Type No. 2, including approaches, loaming, rolling, &c., omplete as specified, at per chain				
4	2	No.	Timber Culverts complete as specified, each				
5	5	days	Labourer, at per day of 8 hours				
6		Item	Provision as per clause........ of General conditions ...		5		

83. Cost of Clearing.—The cost of clearing and grubbing in accordance with the above specification depends altogether on the timber and scrub encountered. The best course in estimating is to make local inquiries as to prices per acre paid for this work, and estimate accordingly, bearing in mind that the presence of fences that must be respected will add more or less to the cost. It is usual to schedule clearing at per chain forward for a definite width.

84. Cost of Formation.—Formation and loaming by road machines or scoops as per Type 1, Fig. 18, in fairly stiff clay, free from large stones, costs, under average conditions, about as under, if the loam can be obtained within 10 chains of the work:—

	s.	d.	
Clearing	3	0	per chain.
22 cubic yards excavation at 2½d.	4	7	„
15 cubic yards loam at 9d.	11	3	„
Rolling and maintenance	1	0	„
Total	19	10	—say £1.

Type 2, Fig. 19, costs about 22s. per chain.

When stuff suitable for loaming is found outside each watertable, so as to be easily put on the formation with the machine, Type 1 can be made for 15s. and Type 2 for about 18s. per chain, inclusive in each case of moderate clearing. Where no loaming at all is necessary, the prices should not exceed, with moderate clearing, about 10s. 6d. and 15s.

The cost of construction in any particular case can be closely estimated by reference to the data in Chapter IV., full allowance being made for local conditions as influenced by cost of horse feed, value of horses and labour, and the hardness or otherwise of the ground.

85. Agents of Destruction.—The effects of climatic conditions and of traffic on road surfaces are fully discussed in § 191, and need not be further referred to here.

86. Maintenance of Earth Roads.—In late summer and early autumn earth roads constructed the previous spring generally require scraping into shape, so as to be ready for consolidation after the first autumn rains. If this work of scraping, however, is left until the end of autumn, the dressing up often does more harm than good by the production of excessive mud. Spring is, however, the best season in which to attend to the general maintenance of earth roads constructed one year or more previously. The principal works of maintenance consist in keeping the surface smooth, in attending to drainage and in preventing the breaking up of the crust as far as possible. The scouring of the surface must be guarded against, and every tendency to gutter checked at its very inception. A smooth surface is necessary to permit of rainwater draining to the watertables as quickly as possible, as any excess of moisture will result in the formation of mud, even if it does not penetrate to the road bed. The surface of a road should in reality form a roof covering to the foundation, and should, therefore, be as nearly impervious as may be. Dust is almost unavoidable on earth roads, as watering them is out of the question. Much can, however, be done towards the mitigation of the dust nuisance by careful maintenance in the direction of preventing the formation of mud after showers. The cheapest and most effective course is to smooth the road when in a moist condition by scraping so as to fill in ruts and prepare an even surface for summer traffic. No machine is more suited to the work of scraping than the road machine described in § 64, and illustrated in Figs. 15 and 23. Work should be begun at the side so that the scraping may be inwards; ploughing should seldom be required, as the object sought is usually to smooth, not to reshape, the road. The blades should be set almost, but not quite, square with the direction of travel, so that plenty of earth is dragged along to fill up the deeper ruts. As a general rule, two traverses over any particular part of the road are sufficient, but care must be taken that "shoulders" or high flanks are not left to obstruct the drainage from the centre. Rolling is of very little use, except for new earth roads, and late spring rains should not be relied upon to set the surface. An effective form of scraper is that known as the "split-log drag," shown in Fig. 27. The holes in the front log are bored so as to give the face a slight cant forward; the face of the rear log is vertical. The drag is hauled by chains arranged with a long and a short hitch, so that the implement will travel at an angle with the direction of the road. If the drag cuts into the surface too much the angle of travel can be varied by shortening the hitch. A board platform indicated by broken lines in the drawing is nailed to the cross pieces for the driver to stand

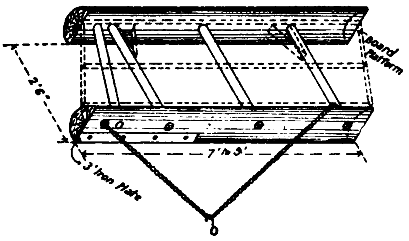


Fig. 27.
Split-log Drag for Earth Roads.

upon. In the absence of a road machine or split-log drag, fairly good work can be done when the road is slightly moist with a V-scraper, or by dragging a rolled steel joist, say 9 in. x 4 in., or a flat-footed 60-lb. Vignoles rail. Scraping a worn-out road is useless; it is far better to add loam as a wearing surface than to scrape the clayey flanks to the centre of the road. It is too often forgotten that material is washed away by rains or blown about as dust until the formation really becomes worn out, just as a metalled road does, and needs a new coat.

A mistake very often made is to fill ruts with material either harder or softer than that forming the original crust of the road; the certain result of such procedure is the formation of either a hard knob, and two holes where there was originally one, or a weak spot that will turn to mud after the first heavy rain. The remarks in this paragraph as to seasons apply generally to southern Australasia. Where summer is the rainy season the routine is different.

87. **Cost of Scraping.**—A team of six horses with driver and a man expert in the use of a road machine will cost, allowing for repairs, about 40s. per day of eight hours, in which time about three miles of average road 18 ft. wide can be scraped up, making allowances for lost time in small repairs, but not for delays by bad weather. The cost of scraping alone is, therefore, only about 13s. 6d. per mile. If a good many holes have to be filled with loam the cost may reach £1 per mile. It may be confidently asserted that in the maintenance of earth roads none of the operations give such gratifying results as scraping regularly and judiciously in the proper season.

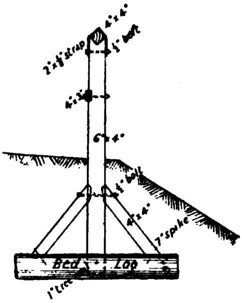


Fig. 28

Fence on an Embankment.

88. **Fencing.**—For the protection of the travelling public fencing is frequently required on roads. The class of fence, whether of split or sawn timber, must be in keeping with the surroundings. Post and rails are far superior to post and wire fences; in fact, there should

be at least a top rail to every fence that is placed close to the carriageway. Wire fences are difficult to see at night, and dangerous in consequence. In all cases barbed wire should be absolutely prohibited. A specimen specification that will serve for a guide is given below for a post, two rail and wire fence.

Fig. 28 shows a sketch of soled and strutted post and two rail fence of sawn timber on a road embankment. Fences of this class should be painted white.

89. Example of Specification for Post and Rail Fencing:—

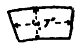
SPECIFICATION referred to in the foregoing Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement (for examples of these see Chap. XVII.), and to be observed in the erection of about.........miles.........chains of post and two rail and wire fence, as described below in the positions shown by locality plan.

Nature of Contract.—It is to be clearly understood that this is a Schedule of Rates Contract, that the length of lines scheduled to be fenced may be increased or decreased on the order of the engineer by not more than 33 per cent., and that payment will be made at scheduled rates only for the work actually ordered.

Site of Works.—The lines to be fenced are approximately shown in red colour on the locality plan and will be set out for the contractor by the engineer, who reserves to himself the right to make small alterations in the position of such lines. No fence must be commenced before the contractor has assured himself by reference to the engineer that the line which he proposes to work upon is the correct one, as no payments will be made for fencing erected in incorrect positions

Clearing.—The line to be fenced is to be cleared above ground of all living or dead trees, stumps, rocks or any other obstructions, to such a width as will allow of the erection of the fence on the lines set out, without any deviations. The top of the fence is to be in a series of straight lines or regular curves, and small inequalities of the ground are to be removed by cutting away or filling up as the case may require, so that the bottom rail may be at a uniform distance above the adjusted surface. [Fencing in road works is frequently in such positions, as for instance along embankments, that no clearing is required.]

Posts are to be of split grey box, ironbark, red gum [the timber specified will be the most suitable obtainable in the district], backed off, clean, sound and free from large knots, splinters, gum veins or other imperfections, and are to be well charred for the lower half of their length. They are to be not less than 6′ 6″ long, 4′ 6″ of which will be above ground, and they must not at the smallest part be of less dimensions



than 7″ x 3″ as sketched in the margin, properly mortised 5″ x 2″ as sketched, and bored to receive three wires which will be spaced to template to be approved of by the engineer. The wires are to be of the best steel No. 8 gauge, black, thoroughly well strained and properly knotted and secured.

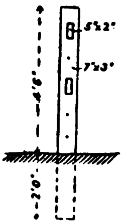


FIG. 29.

At all ends, angles, openings, gates and wickets, or abrupt changes of grade, and at intervals of not more than 5 chains, round posts, not less than 14 inches in diameter at any part, and of the timber specified above, are to be provided. They are to be 7 feet long and 2′ 6″ in the ground, and properly fitted and mortised to receive rails. Split posts are to be spaced 8′ 3″ centres, eight to the chain, and are to be not less than 2 feet in the ground, the earth round them being thoroughly well rammed and consolidated.

Should the contractor, when sinking holes, come upon stone, stumps, roots of trees or any other obstructions, it is to be removed to the depth specified and the hole again filled with good material and rammed round the posts so as to secure it firmly in the ground.

Rails are to be split from approved straight grained hardwood [Specify varieties], clean and free from knots or splinters, and not less in dimensions in any part than 7 inches by 2½ inches and 1 inch, as shown by sketch in margin, and 9 feet in length. They are to be firmly and neatly fitted into the mortise holes, care being taken not to split the posts.

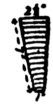


FIG. 30.

90. **Oiling Earth Roads.**—In this country the use of oil on road surfaces has not as yet passed out of the experimental stage. The few trials that have been made have not given very encouraging results, possibly because the right kind of oil has not in all cases been used. Experience in America has proved conclusively that crude oil suited to the purpose must contain at least 50 per cent. of asphaltum, and that it must be obtainable at cheap rates. Crude oils wanting in the necessary asphaltum ingredients evaporate quickly, and are consequently too costly. Much success has attended the use of oil in California, where it was originally laid down in 1898, as a substitute for water, to keep dust from rising. It was found to be an excellent dust layer, and engineers were soon led to use oil of the same quality for binding permanent earth road surfaces. Up to the present about 4000 miles are said to have been treated in that State alone. Metalled surfaces, as well as earth and gravelled roads, can be oiled with advantage, but the special field of usefulness appears to lie in the preservation of the two latter, more especially in dry districts, where trouble is experienced in keeping the surface together

in hot weather. If a cheap oil of the right composition could be obtained here, there is little doubt that it would be invaluable on the earth roads of our semi-arid districts. Future experiments in oiling earth roads should, we think, be carried out on the lines of the latest Californian practice somewhat as follows:—

Heavy asphaltic oil is incorporated with the earth by ploughing and scarifying, and finally compressed with what is termed a tamping roller. The road is roughly formed, then ploughed and pulverised, after which oil to the extent of 2 gals. per sq. yd. is sprinkled evenly from water carts. As the sprinkling proceeds, the surface is scarified and stirred to a depth of 6 in. to ensure thorough impregnation of the earth by the oil. The entire roadway is then reploughed 6 in. deep, and another gallon per sq. yd. applied and worked in. The next procedure is to tamp the road and water tables solid to the surface with a reversible tamping roller weighing about 2½ tons, consisting of fourteen sectors, from each of which are projecting cast steel teeth, staggered, and shaped as sketched in Fig 31. During the rolling process, but not before, water is applied in moderate quantities to assist in packing the earth under the tamper and to prevent clogging. The surface is finally trimmed and rolled smooth, and the result is an oil-paved dustless road, similar in appearance to asphaltum pavement, that is said to endure for years under the heaviest traffic. Watertables in the same construction, when finished smooth and evenly graded, are unaffected by severe rain storms. The average cost per sq. yd. at Santa Monica, California, ranges from 8d. to 1s., where the cutting or filling does not exceed 1 ft. For remarks on the use of oil as a dust-layer, see § 277.

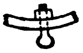


FIG. 31.

CHAPTER VI.

GRAVELLED ROADS.

91. In a number of districts in Australasia gravel can be readily obtained where very little solid stone suitable for breaking into road metal is available. Gravel of the right quality gives a much harder and more durable crust than the best loam, and when properly applied makes a splendid road for light traffic. Where the traffic is heavy it will, as pointed out in § 15, generally be cheaper in the long run to use broken stone, at any rate, for the wearing coat.

Gravel is an accumulation of fragments of stone from the size of a pea up to that of a duck egg, generally rounded to some extent by the action of water or ice, and occurring in beds closely intermixed with clay, sand, or other materials. Deposits occur in geological formations of all ages from Silurian to Post-pliocene, and, as may be expected, contain fragments of all kinds of rock, including shale, slate, mudstone, granite, basalt, sandstone, limestone, ironstone, quartzite, quartz, &c. Water-worn quartz pebbles are common in gravels, especially those of more recent origin.

92. **Qualities of Gravel.**—The quality can be judged by an inspection of the gravel pit. If hard and compact *in situ*, and requiring to be loosened by a pick before removal, it will certainly set well under traffic. The allowable size of the largest stone depends on its hardness; soft stones crack and break under traffic; hard ones do not fracture, but they make a rough road even if they do not work loose, as they generally do, if at all flaky. Hard pebbles should not exceed 1½ in. greatest dimension, and anything over this size should be screened out or broken down; 2 in. is allowable in softer gravels. A variety of sizes is desirable in a gravel, as the voids are thereby reduced, and the quantity of natural binder, always an element of weakness, is a minimum. The binder, whether clay, sand, loam, dust, or iron oxide, should not be in excess of the amount required to fill the voids, which range between 25 per cent. and 30 per cent. Any excess of clay,

loam, or sand over 30 per cent. must, therefore, be screened out of a gravel before it can be considered suitable for road building. Gravels which do not contain more than the allowable percentage of fines may, if suitable in other respects, be applied directly to the road surface. Screening in small quantities is effected by throwing the gravel against a fixed inclined wire screen of suitable mesh. If a large quantity has to be treated it will pay to pass it through a power-driven rotary screen of the type used for screening crushed stone, and described in § 144, and illustrated in Figs. 50 and 51. As a general rule, gravel containing rough angular fragments knits well, and makes a better surface than one composed of rounded stones. Much depends on the binding qualities; in fact, one of the chief requirements of a gravel is a strong natural cementing property. River gravel, more properly termed shingle, has been found to be a bad setting material, owing to the absence of cementitious matter. Pit gravel, on the other hand, as exemplified by the well-known Mangalore gravel of Victoria, often contains a good deal of iron oxide among the fines, and generally sets and wears well under moderate traffic, although it consists almost wholly of rounded quartz pebbles. Silurian gravel, consisting mostly of angular fragments of disintegrated Silurian rock but little waterworn, is of common occurrence in all our Silurian areas, and its value also has been found to depend largely on the percentage of iron oxide present in it. Clay is the most common natural binder found in gravels; unless of a ferruginous or highly siliceous nature it is not satisfactory, as it becomes greasy, and loses its binding properties in wet weather. Ferruginous gravels possess, to a marked extent, the property of re-cementation after being broken up; in fact, they often set harder than in their original bed. Most gravel beds are covered with surface soil, unsuited for road-building, which must not be mixed with gravel, and which should be stripped and removed as the work of excavation proceeds. It can be thrown back over the worked-out portions of the pit, and the surface soil thus practically replaced. By careful stripping and backfilling, gravel deposits can be removed without destroying land for agricultural or grazing purposes. The greatest fault of gravelled roads in Australia lies in the miserably poor material with which they are too often constructed. How much better it would be to expend a little more money in providing suitable gravel or stone, and in screening out sand and dust, than to attempt to make roads with stuff that is really nothing but loam interspersed with a few pebbles. Nothing but disappointment can result from a continuance of its use, and the sooner this obvious fact is generally realised the better it will be.

93. **Weight of Gravel.**—A cubic yard of ordinary pit gravel weighs about 3300 lbs. when moist. When dry it weighs about 5 per cent. less, and when very wet about 10 per cent. more than when only slightly moist.

94. **Foundation.**—A well-prepared earth road makes an excellent foundation for the class of highway under discussion. Surface and subsoil drainage are a necessity in wet locations, and should be carried out as described in § 70, and specified in § 179. It is only wasting material to spread gravel or metal on wet spongy places without forming the road or making provision for carrying off the water. If the formation is soft, the wheels force the gravel into the foundation, and cause the clay to be pushed up between the stones, as shown in Fig. 32. There are two ways of preparing a road for the reception of gravel or metal. One is to excavate or "box out" a trench of the same depth as the thickness of the coat to be applied; the other is to spread the gravel directly on the earth formation, and to fill up the flanks or shoulders to the grade decided upon in the cross section. Except in sandy country there are several objections to boxing the formation, the principal being—(a) that the already well consolidated earth formation is destroyed, and what was probably a good foundation spoilt; (b) that in retentive clay the boxing forms a receptacle in which water lodges to the detriment of the road surface; (c) that the cost of cutting and disposal of the excavated material is often very great. With proper construction, sand makes a good foundation for a gravel crust, and as trouble need not be expected

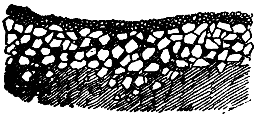


Fig. 32.
Showing the Effect of a Soft Foundation.

from drainage, the two first-mentioned objections do not apply in light porous soils. Except in the construction of new roads on pervious ground, it is not good policy to go to the expense of boxing. In all cases the formation, unless previously well trafficked, should be thoroughly consolidated by rolling. If a steam roller is available it should be used, provided that the foundation is firm enough to carry it. Sometimes a horse roller is as heavy an implement as can be taken on to a newly-made earth formation. Any depressions that appear during the rolling of the sub-grade should be filled and rerolled before any gravel is spread; it is more economical to make up inequalities in the foundations than to add material to the finished surface of the road; besides, unequal depths of gravel on a road are sure to cause it to be uneven, and cups will develop where the gravel is thinnest.

95. **Cross Section.**—The surface of a gravel road should slope outwards from the centre, but excessive crown must be avoided, for reasons given in §§ 71 and 159. The side slopes need not be so great as in an earth formation, as harder surfaces drain more readily; in fact, the better the gravel the less the slope required; 1 in 20 is suitable in a country road, but 1 in 30 is about right on a suburban street. The best profile for the crown will be discussed in § 160, Chapter IX., on metalled roads. It may be mentioned here, however, that the engineer in designing his cross section should look forward to the time when the centre of this gravelled strip shall have worn down 2 or 3 in., and see that when that occurs there shall still be enough fall to the watertables.

96. **Width and Thickness of Gravel.**—Gravel strips are laid as narrow as 8 ft., with turnouts at every few hundred feet, where the gravelling is widened to allow of loaded vehicles passing. It is much better, where the traffic will warrant the expense, to put down 12 or 14 ft. of gravel in preference to a narrower strip. The drier the foundation the thinner the coating of gravel required to distribute the wheel loads. If the foundation is poor, 10 in. of gravel cannot be regarded as excessively thick. On solid ground 8 in., or even 6 in., will make a very good road if laid and rolled in layers.

97. **Spreading.**—Gravel can, without danger of unequal settlement, be spread on an earth foundation, whether clay or sandy loam, provided that such foundation has been well consolidated by traffic or rolling. Where several grades of gravel can be got, the coarsest should be placed in the lowest layer to such a depth that when rolled its thickness will be 3 in. or 4 in. Gravel may be dumped in heaps directly on to the formation and levelled with a shovel, by a road machine, or by some improvised grader. Spreading from plates, as recommended in § 171, though desirable, is scarcely required with this class of material. When it is laid on almost pure sand, trouble is generally experienced, owing to the sinkage of the stones into the formation under the weight of even a light roller. Strips of hessian or other cheap cloth have been successfully laid as a covering to the sand before the gravel is put down. The cloth, which need not be of durable quality, can be obtained at a cost of about 2d. per square yard, or considerably less than the value of a 2-in. layer of metal forced into the sand and wasted. A layer of straw spread about 4 in. thick prevents the mixing of the gravel with the sand, and can be used instead of cloth.

98. **Rolling the Surface.**—It must be remembered that the percentage of voids in gravel of average quality is smaller than in broken stone, and that the compression secured by thorough rolling does not amount to more than 12 per cent. of its bulk when loose. During rolling, however, quite another 12 per cent. of the stones are usually forced into the earth or sand formation below, so that the total loss may be set down at one-fourth, from which we find that 1 1-3 cubic yards of loose corresponds to 1 cubic yard of compact gravel. A steam roller should be used whenever available, provided that the material is able to carry its weight on the newly-spread material. A horse roller is sometimes used to partially consolidate the crust, and the steamer sent along afterwards. The trouble with gravel deficient in binder is that it is pushed along in front of a roller. Rolling should be undertaken when the gravel is damp; if too dry, it will be necessary to water or wait for rain. The roller should not be used on layers over 6 in. thick, or proper consolidation cannot be secured.

Inequalities appearing in the surface during the rolling process must be made up with similar material as the work proceeds.

It has been the practice in certain Victorian shires to use for gravelling roads carts with tires about 13 in. wide, and with clear spaces between insides of wheels of something under 5 ft. The specifications provided that the gravel should be carted in these over that already spread, and the result is only too apparent in the shape of the roads so made, which have a central ridge about 4 ft. wide, and standing 3 to 4 in. above the wheel tracks on each side of it. The consequence of this mode of rolling is that each animal of a pair horse team is running on a sharp side slope, most uncomfortably, and so as to cause great liability to lameness. As pair horse buggy teams are the rule in Australia, the practice cannot be too strongly condemned. The road should be evenly rolled all over, but this result is highly improbable if roller carts such as described above are used on gravelled strips 9 or 10 ft. wide.

99. **Binding.**—In most gravel deposits there is a sufficiency of natural binding material, and in many it is necessary, as pointed out in § 92, to screen out the excess. Gravels are, however, found in which there is an almost total absence of fine stuff. If the pebbles are at all soft and likely to break down under rolling and traffic, it is inadvisable to add binding material, but if they are hard some must be used as on a metalled road. See §§ 174 to 178, Chapter IX.

100.—**Measurement.**—Gravel can be measured (a) in the pit, (b) in wagons, or in trucks if transported by rail, (c) on the road. Measurement in the pit is not always practicable, especially if two or more contracts are being supplied at the one time, or if the deposit or excavation is irregular. Measurements can be accurately made in railway trucks, but the specifications must distinctly state whether the depth will be taken at the loading or delivery station, as gravel shakes down in transport as much as 5 per cent. It is difficult to measure the content of drays and wagons if the load is piled up above the sides of the cart; it can be done with fair accuracy, however, and this is often the most practicable way of arriving at the quantities. On small road jobs, where a clerk of works is not regularly employed to check the loads, measurement on the road must be resorted to. Some engineers insist on the gravel being placed in a long heap on the formation, squared up to template, to facilitate measurement before spreading; others compute the quantity by dipping when the gravel is spread. Either method has its advantages. The first is the more accurate, but is costly on account of the extra labour in stacking and trimming. The second is more approximate, and the results are open to considerable doubt, especially if the dipping is done after rolling, when the gravel has been more or less compressed and a certain indefinite amount of stone forced into the formation below; for these reasons dippings should, in fairness to all parties, be taken before rolling. Contractors should be specially careful to ascertain before tendering the method of measurement to be adopted. Some engineers require the formation or subgrade to be graded exactly, and enough material added to bring the finished surface up to the final road grade, as shown on drawings. The fact that 2 in. or more of stone may be compressed into a loose foundation is, in such a case, a most important factor, and one that must not be overlooked when fixing prices.

TABLE IX.

Showing the number of cubic yards of compacted gravel or metal per lineal chain. The within quantities should be increased by one-third to give the corresponding number of cubic yards of loose material, whether gravel or broken stone.

WIDTH.	5″ Deep.	6″ Deep.	7″ Deep.	8″ Deep.	9″ Deep.	10″ Deep.	11″ Deep.
	Cub. Yds.	Cub. Yds.	Cub. Yds.	Cub. Yds.	Cub. Yds	Cub. Yds.	Cub. Yds.
8 feet	8.15	9.77	11.41	13.04	14.66	16.29	17.93
9 ,,	9.17	11.00	12.83	14.66	16.50	18.33	20.16
10 ,,	10.18	12.22	14.26	16.29	18.33	20.37	22.40
11 ,,	11.20	13.44	15.68	17.92	20.16	22.40	24.64
12 ,,	12.22	14.66	17.11	19.55	21.99	24.44	26.88
14 ,,	14.26	17.12	19.96	22.81	25.66	28.51	31.36
16 ,,	16.30	19.54	22.82	26.07	29.32	32.58	35.86
18 ,,	18.34	22.00	25.66	29.32	33.00	36.66	40.32
20 ,,	20.36	24.44	28.52	32.58	36.66	40.74	44.80
22 ,,	22.40	26.88	31.36	35.84	40.32	44.80	49.28
24 ,,	24.44	29.32	34.22	39.10	43.98	48.88	53.76

101. Example of Specification for a Gravelled Road in a Country District.

SPECIFICATION referred to in the foregoing Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement* and to be observed in the construction of gravelled road as shown by plans attached hereto.

General Description.—The works of this contract consist of the clearing, forming, cross drainage and gravelling of 40 chains of road, situated as shown by locality plan. They include the preparation of all foundations, cuttings and embankments shown by drawings supplied, or to be supplied to the contractor, and the construction of all culverts and sub-drainage works that may be ordered.

Nature of Contract.—It is to be clearly understood that this is a Schedule of Rates Contract, that the length of road to be made, the quantity of gravel to be spread, the number of culverts to be built, and any of the items in the schedule may be varied as decided by the engineer, and that payment will be made at scheduled rates, only for the work actually ordered and executed. Any work ordered but not scheduled must be carried out and paid for under Clause...... of the "General Conditions of Contract."

Clearing.—[On plains where there are neither trees nor stones, no clearing clause is necessary. Where road has never been cleared insert specification for clearing, contained in Chapter V., § 82. Where road has been previously cleared insert the following:—] "The roads to be formed have been cleared, but all saplings, roots, or stumps that may, in the opinion of the engineer, require removal must be grubbed out or burnt off or removed by the contractor, the cost being included in the scheduled price for formation.

Formation.—The formation is to be in accordance with the drawings attached, or to be supplied, and great care must be taken to adhere closely to longitudinal profiles and cross sections. All holes, from which trees, stumps, rocks, roots, &c., have been removed, must be completely filled with approved material, well rammed, or otherwise consolidated.

Embankments are to be carried out in such a manner as to ensure their being, when thoroughly consolidated, of the specified dimensions, as shown on drawings; and, in carrying an embankment over any bridge or culvert, provision must be made for bringing it up equally on both sides of such bridge or culvert, and so consolidating it that the weight of the earth may be properly distributed. In sidelong ground, or in adding to existing embankments, slopes must be benched to prevent slips.

Any extra material that may be found to be necessary for embanking may be obtained from borrow pits at points to be selected by the engineer anywhere within a lead of.........chains from the centre of the bank under construction, or the engineer may order the slopes of the cuttings at certain places to be flattened, so as to provide additional stuff.

---

* For specimens of these see Chapter XVII.

The consolidation of the embankments must be effected by thorough trafficking when under construction, and rolling with a roller weighing not less than 150 lbs. to each inch of breadth. This rolling will be paid by time at the rates scheduled. In addition to the provision just mentioned for consolidation, an allowance of 1 inch per foot of height of bank must be made for eventual subsidence. Great care must be taken not to disturb any survey or level pegs, or bench marks, and none of these are to be removed until the engineer or his representative shall approve of this being done. Where required, "buoys" are to be left standing, with the turf undisturbed, to facilitate the measurements.

Every contractor must provide himself with the necessary appliances, such as spirit-level, straight-edge, &c., to enable him to obtain accurate boning points from pegs or bench marks near his works.

Re-formation.—[Where the road to be metalled has been originally formed in earth, the following clause may be substituted for the one immediately preceding:—]

The formation to receive the metal must be brought into the shape shown by cross sections with good sound earth, and the whole must be well consolidated by rolling before any stone is spread thereon. On no account must stone be spread in mud or water, and every care must be taken to secure a solid bed for the metal. Water-tables must be accurately graded according to longitudinal sections, so as to secure proper drainage, and flanks neatly trimmed in accordance with drawings.

Subsoil Drainage.—Where the engineer considers that such are necessary, subsoil drains in accordance with following description and the sketch attached [To be as per Fig. 16] are to be constructed, and these will be paid for at the rate mentioned in the schedule:—Three-inch agricultural drain pipes are to be laid with their ends abutting in trenches of the dimensions sketched, evenly graded with a fall of at least 2 inches, but not more than 1 foot per chain to an approved outfall. They are to be covered with 6 inches of clean well-screened metal of 3-inch gauge, overlaid with a layer of 3 inches of finer metal or gravel of not more than 1½-inch gauge; thence to the formation level or subgrade the trench is to be filled with earth well consolidated.

Cross Drainage.—Where shown on plans, culverts are to be constructed of the types scheduled for the various points, and those will be paid for at scheduled rates. [These culverts will be built from type drawings prepared in accordance with the class of material available in the district in which the work is going on. See Chap. XV. for sketches and specifications.]

Gravel.—[If Silurian gravel is not to be used, this clause must be varied.] The gravel or stone is to be of the best quality of Silurian gravel. It is to be free from all earth and vegetable matter, and screened over a ¾-inch screen when the stuff is dry, and is to have no stones larger than 3-inch gauge. Each tenderer is to send in with his offer a sample, not less than 56 lbs. in weight, of the stone he is prepared to supply. This sample, in the case of the accepted tenderer, will be kept for comparison with the stuff supplied.

All material which, in the opinion of the engineer, is not up to the specification and sample will be rejected, and the Council will not be responsible for any loss of any kind that the contractor may suffer on account of rejected material. [See Chap. IX. as to gauges for various classes of stone.]

Delivery and Measurement.—The gravel will be brought by rail to the............railway station and carted out and spread by the contractor, it being distinctly understood that the Council accepts no responsibility for freight, demurrage, or railway charges of any kind either on accepted or rejected material. Stone not up to specification will be rejected, and must not be carted out on the road.

The gravel will be trimmed in the trucks by the contractor so as to be easily and accurately measured by the engineer or his representative before being unloaded, the contractor being present if he so desires. Payments will be made on truck measurement at the delivery station. The quantity to be spread will be.........cubic yards per chain lineal with a width of.........feet as shown by drawings. (Should the gravel be brought by wagons or carts direct from the quarry to the road on which it is to be spread, measurements will be made in the vehicles used for its transport, which must be uniformly loaded by the contractor, and examined and tallied in by the Clerk of Works before being tipped for spreading.)

Spreading.—The gravel is to be dumped in heaps on the formation and evenly levelled with shovels or a road machine to the widths and thicknesses shown on drawings.

Rolling.—When the gravel has been spread as above, it must be rolled as many traverses as the engineer may direct, using a roller of the weight per inch mentioned in Clause.........above, any irregularities being made good as they appear by adding fresh gravel from small heaps laid aside for the purpose.

The roller must be horsed as per schedule with four heavy staunch draught horses, walking at the rate of not less than two miles per hour, and driven by a competent and able-bodied driver. The contractor will be paid for rolling at scheduled rates, with the proviso that he shall not be called upon to undertake rolling for any period less than half a day. From the completion of the work to the expiration of the maintenance period the contractor shall, on receipt of three days' notice from the engineer, again roll the road as before, the minimum period in this case being one full day. [Should the municipality own a motor roller it is generally better that rolling be done by its own staff, in which case the above clause would be altered accordingly.]

Maintenance.—The contractor is to keep the whole of the work in proper repair to the satisfaction of the engineer for two months from the date of completion, any ruts or inequalities that may appear being made good.

Every expense incurred by the contractor in maintenance must be considered to be included in the scheduled prices for the various classes of work. The deposit security will be paid to the contractor when the engineer shall certify that the maintenance has been satisfactorily completed.

SCHEDULE.

No.	Quantities.	Description of Work.	Rate.	Amount.		
				£	s.	d.
1	40 chains	*Clearing of road complete, as specified, at per chain				
2	40 ,,	Formation of road, as per drawings, complete as specified, at per chain				
3	200 lin. yds.	Subsoil drain complete, as specified, at per yard				
4	3 No.	Culverts, Type A, as per drawings, complete, at per culvert				
5	978 cub. yds.	Silurian gravel provided and spread as specified, at per cubic yard ...				
6	8 days	Rolling, with driver, team of four horses and roller, as per specification, during construction of works and maintenance period, at per day of eight hours ...				
7	3 days	Labourer in opening up, or any other work that may be ordered, at per day of eight hours... ...				
8	Item	†Provision for extra work, as per clause......of General Conditions		15	0	0

* If road has been previously cleared omit this item. † The amount will vary with the estimated cost, &c., of the works.

102. **Cost of Gravelled Roads.**—The cost of earthwork in the watertables and formation has been discussed in Chapters IV. and V. The cost per cubic yard of gravel laid and rolled for an average case, with cartage of two miles, is itemised below. Cost of surveys and engineering design and supervision, as well as contractor's profit, must be added. By varying the amounts to suit local conditions, and, if necessary, adding railway freight, the expense of loading and unloading trucks, and of screening if required, the cost per cubic yard of loose gravel for any particular case can be closely estimated. See explanatory note to Table IX. for the relation between the volumes of loose and compacted gravel.

	Per Cubic Yard.	
	s.	d.
Royalty payable to the owner of the gravel pit	0	3
Stripping surface of pit (very variable) ..	0	2
Loosening and loading into drays	0	6
Cartage two miles, drays returning empty ..	1	6
Spreading and trimming	0	3
Rolling and maintenance for two months ..	0	9
	3	5

The cost of hand-screening once through a sieve adds from 6d. to 9d. to the price per cubic yard.

103. **Maintenance.**—The considerations mentioned in Chapter V. on earth roads are mostly applicable to gravel roads, which, when newly constructed, do not set hard for some time; in their first stages they need careful attention, as ruts are sure to appear, and must be filled at once from heaps provided at intervals on the roadside. Where gravel is thus added the road surface should be loosened slightly to secure a good bond. Loose stones should be raked off, and the watertables kept reasonably clean. See §§ 86 and 203, on the use of machinery for trimming the flanks. Washings from the crown accumulate rapidly, and raise the sides of a road considerably, more especially if detritus and dust are intercepted and held by grass growing on them. One of the principal works of maintenance is the trimming of the shoulders at intervals so as to preserve perfect drainage. The question of when best to trim roads and paths is discussed in §§ 86 and 203.

104. **Repairs.**—It will be necessary at intervals of a few years, the exact time depending on the quality of the material, and the nature and volume of the traffic, to recoat the surface by adding a layer of gravel about 3 in. thick, care being taken to provide a cross section of correct shape. Thin coats, applied often, provide a better road than thick layers at long intervals. Rolling should always be insisted upon. Generally, the resurfacing should be as carefully carried out as for a new road.

105. **Cost of Maintenance.**—This depends on the volume and nature of the traffic, the nature of the gravel, and of the subsoil, the climatic conditions, the prices of labour and materials, and the care and skill displayed in doing the work. In ordinary cases the average cost per annum in Australia varies from £10 per mile, 12 ft. wide, where the gravel is good and the traffic light, to £20 where the conditions are more severe. When the cost exceeds the larger sum the use of more lasting material should be seriously considered on the lines indicated in Chapter II.

CHAPTER VII.

ROLLERS AND SCARIFIERS.

106. Road rollers are comparatively modern inventions, having come into use long after the days of Macadam. The earlier type of horse-drawn roller still survives, and serves its purpose in localities where earth roads are the vogue, though not so effectively as the improved reversible horse roller referred to below. Steam rollers have supplanted horse rollers in most cities, as well as in a few of the more progressive shires having 30 miles or more of metalled roads to maintain. The most recent type, and the one that is most likely to be useful in places where water and coal are scarce, is the motor roller driven by petrol or oil. For light work, such as pavement construction, motor rollers of a type to be described below are particularly applicable.

While it is a matter for regret that power-driven rollers have not been more generally adopted in Australasia, it is satisfactory to note that many municipal authorities are at last making efforts to secure up-to-date machinery. The advantages pertaining to the use of rollers, as well as the weights desirable under varying conditions, will be discussed in Chapter IX., and need not be here considered at length. The desirableness of two or more very small adjacent municipalities combining to purchase the more expensive implements should not, however, be lost sight of.

107. Types of Steam Rollers.—The well-known locomotive boiler type has been adopted by English makers, to the practical exclusion of all others. In America vertical boiler rollers have been largely manufactured, in addition to the first-mentioned pattern. The only merits possessed by the vertical type are their adaptability to steep slopes and their somewhat lower cost. If care be taken to maintain the water level in the horizontal boilers as now turned out, they are quite safe on grades of 1 in 8, and it is only when steeper slopes have to be negotiated that the purchase of the vertical type should be decided on. As to general requirements, every steam roller should be capable not only of climbing 1 in 10 gradients over loose metal, but of maintaining a sufficient pressure of steam for that purpose on long hills.

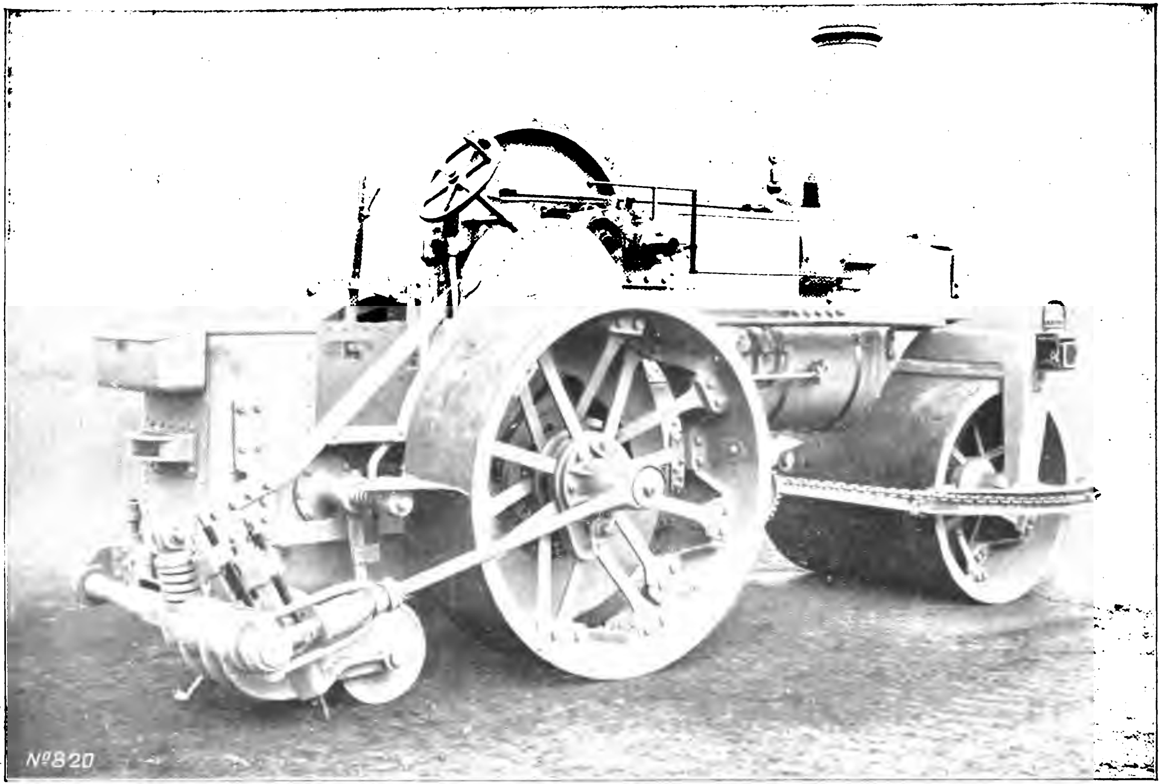


Fig. 33.—Bomford Patent Spring Scarifier, mounted on 10-ton Steam Roller.

To face p. 109.

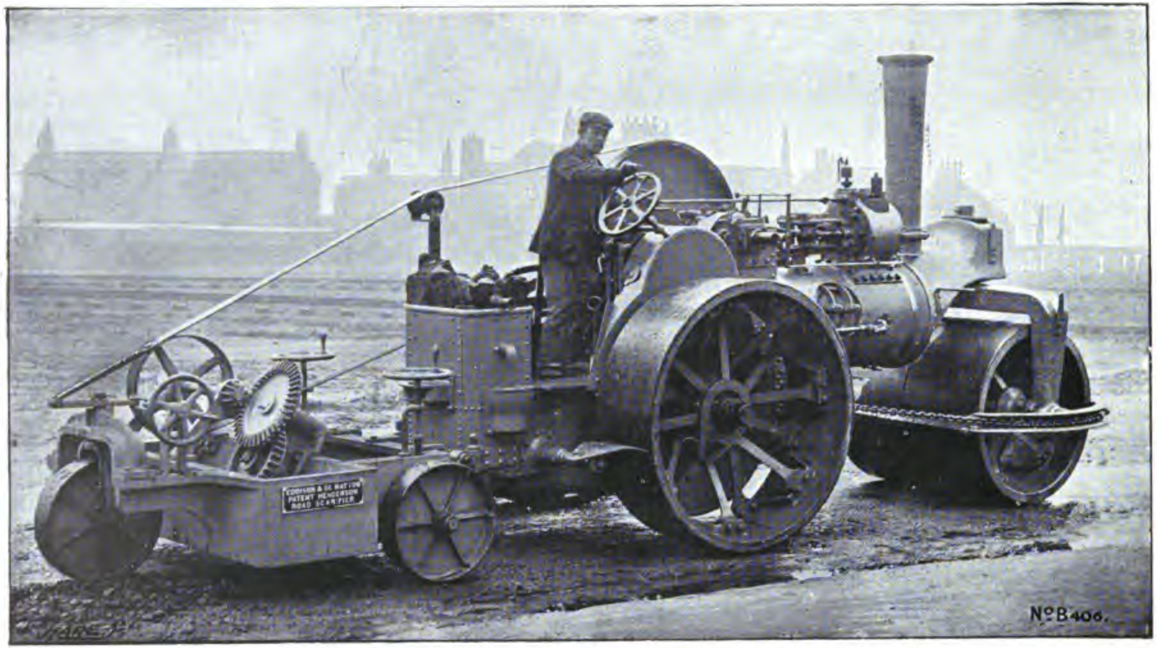


Fig. 34.
Fowler-Henderson Patent Steam Scarifier, with Revolving Drills.

It is quite a mistake to suppose that steam rollers can be used for no other purpose than road rolling. A steam roller is practically a traction engine mounted on broad wheels, and as such can be used for hauling a road scarifier or for dragging a stone breaker from place to place. When the driving gear is thrown out of operation we have practically a portable engine capable of driving any belt-driven machinery, including rock breakers, road scarifiers of certain types, pumps, and saw mills. A few leading makers are turning out convertible rollers, which may be transformed into traction engines by changing the smoke box and forecarriage and the rear rollers or wheels. This type of engine, illustrated by Fig. 36, is particularly useful in country shires for hauling road machines, wagons, &c., as well as for rolling the broken stone, and will, when its merits are known, be widely adopted.

108. Compound Rollers.—Steam rollers are fitted with single or compound cylinders, as required by the purchaser. The advantages of compounding include the saving of close on 30 per cent. in fuel and water, increase in power, and, as may be expected where there are two cranks in place of one, greater steadiness in running, which tends towards the production of a smooth road surface. By careful design, the steam can be expanded to about eight times its original volume, and exhausted at but little above atmospheric pressure, so that its full elastic force is utilised, while noise, as well as danger from sparks, are greatly reduced. A serious disadvantage of single-cylinder engines, but absent in those fitted with compound cylinders, is the difficulty in starting the machinery when the crank is on a dead centre. Compound engines are slightly the more expensive, and for this reason both types are still manufactured. The advantages of compounding are, however, so great that, for rollers weighing 10 tons and over, the extra expense is fully warranted.

109. Weights and Dimensions.—Figs. 33 and 34 show the leading features of modern steam rollers with scarifiers attached, as manufactured by John Fowler and Co., of Leeds. They supply rollers weighing 8, 10, 12, 15, and 20 tons, provided with single or compound cylinders as required, and designed for a working boiler pressure of 180 lbs. per square inch.

The latest type of roller turned out by Marshall, Sons and Co. Limited is illustrated in Fig. 35.

These rollers are made in 10-ton, 12½-ton, and 15-ton sizes, the approximate weights of which when full and in working order are 12¾, 14¼, and 16½ tons respectively. The working pressures are 140 lbs. for single cylinder, and 160 lbs. for compound rollers. The diameters of the hind wheels are 5 ft. 4 in., 5 ft. 6 in., and 6 ft., and their widths 16 in., 16 in., and 18 in. respectively, while the extreme width rolled by the compound rollers is 6 ft. 3¾ in., 6 ft. 3¾ in., and 6 ft. 10 in. Marshall's scarifier for attachment to their rollers is described in § 118, and illustrated in Fig. 43a.

The wheel base, or distance between the centres of the front and driving wheels, varies between about 11 ft. in most 10-ton rollers, and 12 ft. 6 in. in 15-ton machines. The weight is not evenly distributed, but about three-fifths of the total is carried by the hind axle. Although leading makers aim at equalising as far as possible the load on the axles, the pressure per inch of width on the driving rollers is about twice that on the front rollers. This information is required by those engaged on the design of bridges and culverts of moderate span. The front rollers should not be of too small a diameter, as in some of the earlier types, or the peripheral speed will be so great as to cause rapid wear, and the machine will, moreover, tend to push the loose metal ahead rather than to consolidate it. In any case the front rollers should overlap the track of the rear rollers by at least 2 in.

Fig. 38 shows a view of the first Australian-made steam roller, which was built for the Collingwood City Council by the Austral Otis Engineering Company Limited, of South Melbourne. The machine is of the latest type, and embodies all recent improvements.

110. **Details of Construction.**—The design of the boiler should comply with Board of Trade requirements in all respects; the holes should be drilled, and the riveting done by hydraulic machinery wherever possible. Before taking delivery of a new steam roller, the boiler should be tested by hydraulic pressure to at least 50 per cent., but not more than 75 per cent., above working pressure. Secondhand boilers

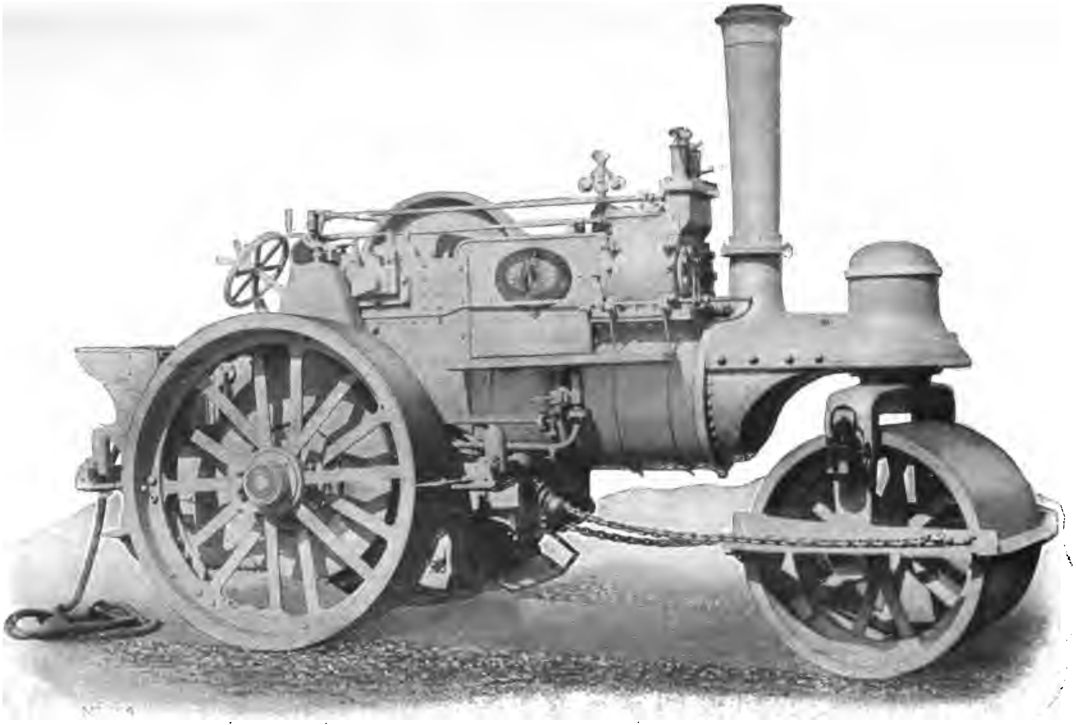


Fig. 35.—Marshall's Steam Roller.

To face p. 110.

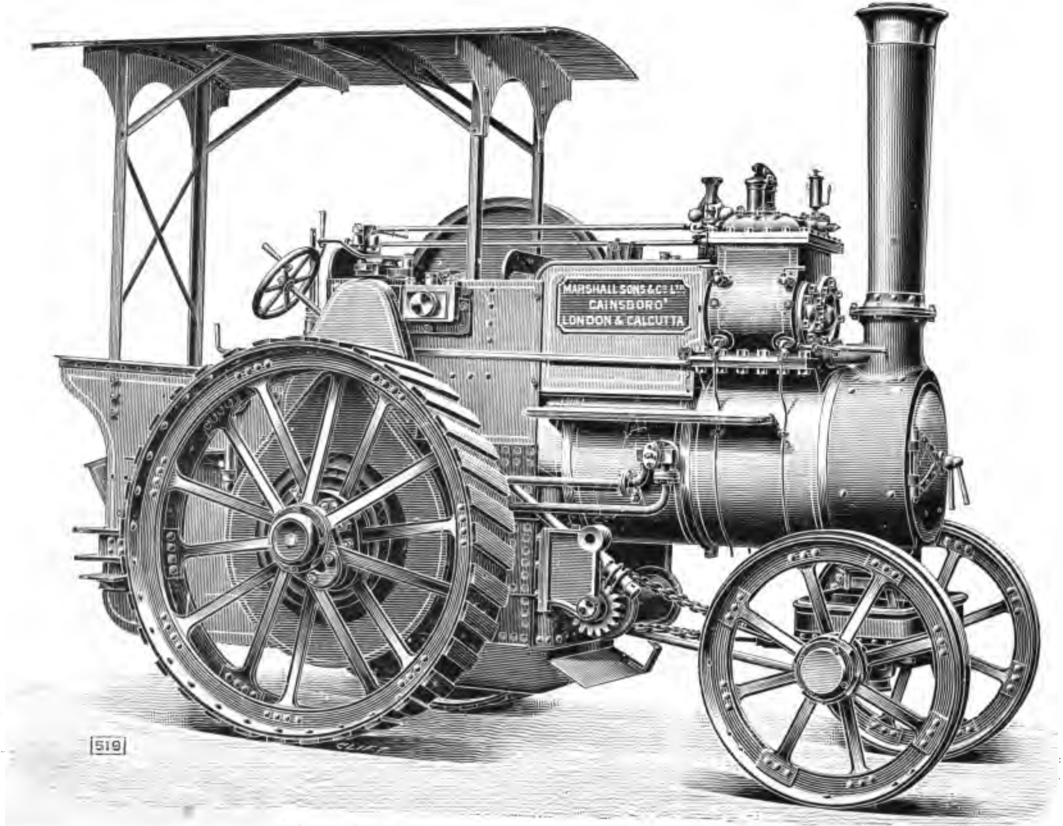


Fig. 36.—Roller Converted to Traction Engine

To face p. 110.

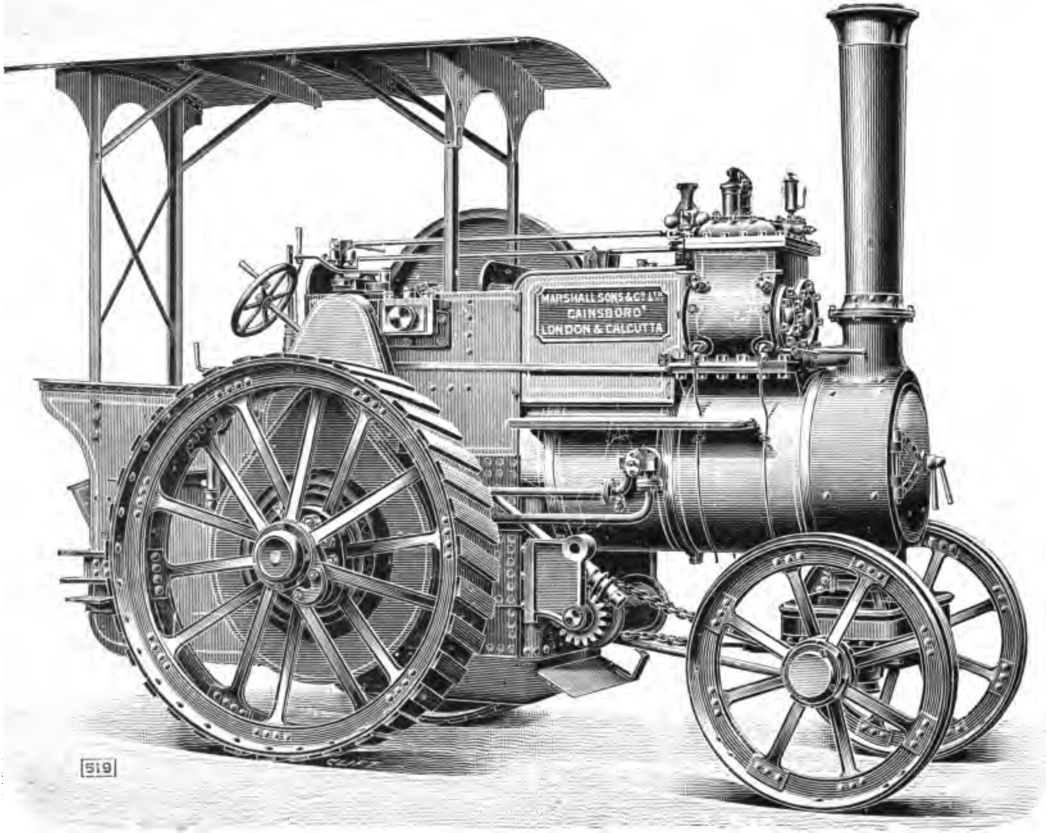


Fig. 36.—Roller Converted to Traction Engine.

To face p. 110.

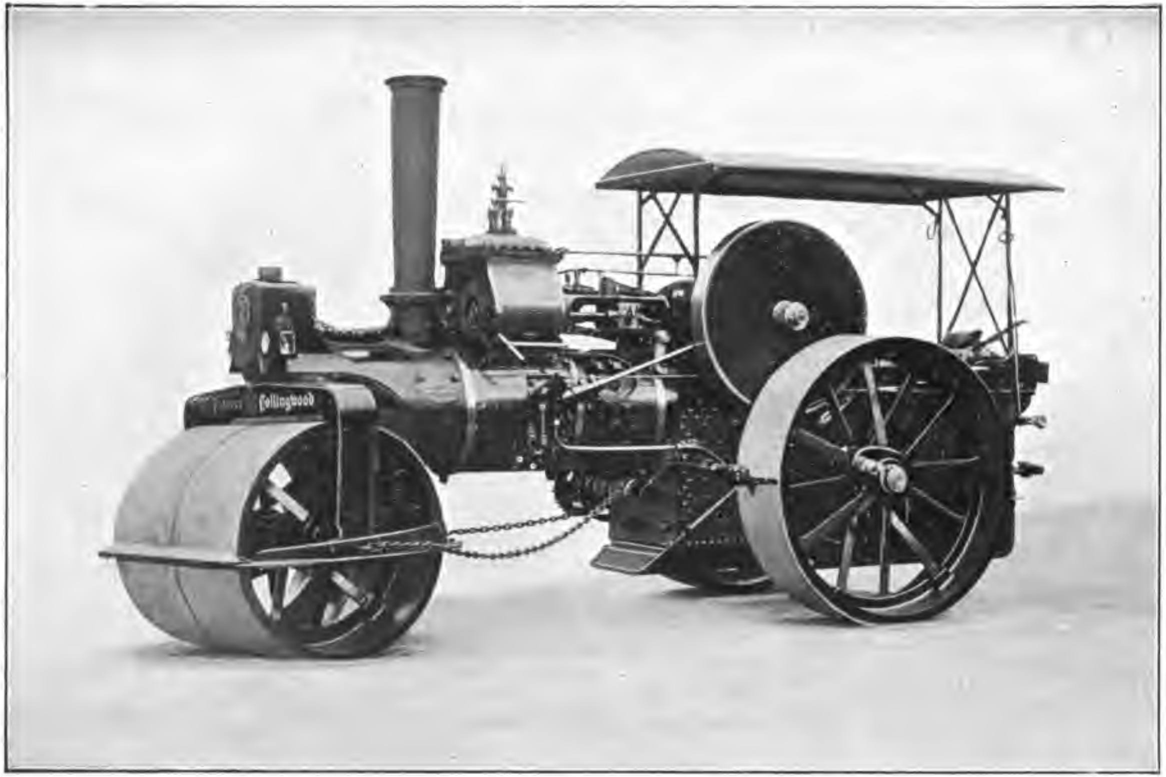


Fig. 38.—First Australian-made Steam Roller.

To face p. 110.

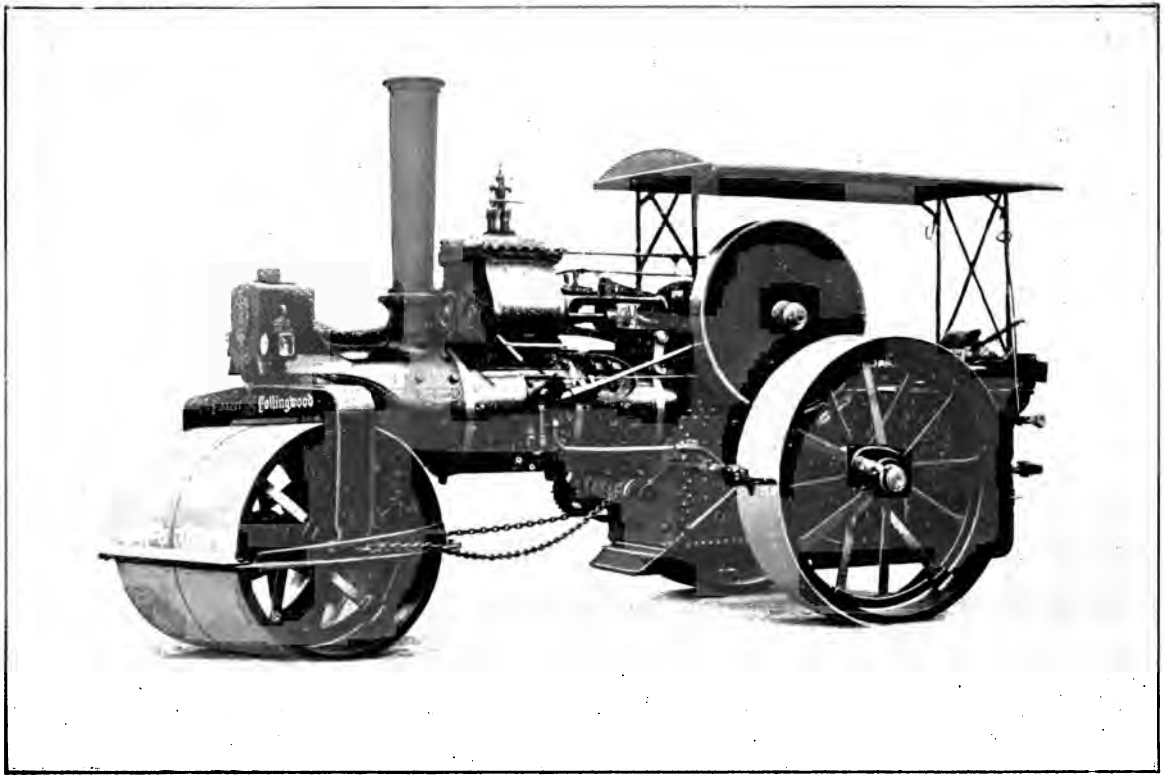


Fig. 38.—First Australian-made Steam Roller.

To face p. 110.

should never be subjected to any such severe strain, or permanent injury may result. A test of 20 per cent. in excess of working pressure is about as far as one should go with an old boiler of any sort. The boiler is generally fed by a short-stroke pump, with gunmetal plunger driven by an eccentric on the crank shaft. An independent direct-acting steam pump is sometimes preferred, as it can be operated when the machinery is at rest. In any case it is always well to provide an injector as an independent feed. Water lifters operated by steam pressure with about 25 ft. of suction hose are useful for filling the engine tank from streams or ponds, though unnecessary where supplies can be drawn from water mains under pressure. Rollers built for use in Australasia should invariably be provided with a galvanised iron awning to protect the driver from the weather. The best makers may be trusted to provide ample grate area and heating surface to ensure that slow and complete combustion, so essential to the suppression of smoke and soot. These, while indicating waste and inefficiency, are particularly objectionable in either business or residential streets. In the selection of a steam roller, importance should be attached to the facilities provided for access to the boiler. Not only must there be ample clearance in front of the smoke box to enable every tube to be easily swept, but wash-out plugs and mud holes doors must be liberally provided, in addition to a manhole affording access to the interior. The importance of keeping the boiler thoroughly cleaned out cannot be over-estimated. The amount of cleansing required depends largely on the quality of the feed water, but it should, under the most favourable circumstances, be attended to at least three times in a rolling season of, say, six months. When the engines are laid up during the off season, the boilers are best preserved by filling them with clean water. Other boiler mountings include a chimney of wrought iron, fire-door with air regulator and baffle plate, steam cocks, water gauges, furnace bars, ashpan, blow-off cock, pressure gauge and whistle. Cylinders cast of the best selected cold blast iron should be tested by hydraulic pressure before fixing, and must be completely jacketed with high-pressure steam. Stephenson's reversing link motion valve gear is almost universally adopted for rollers and traction engines on account of its simplicity and efficiency. The durability of working parts, such as those of the valve gear, is greatly enhanced by case-hardening. Solid fly-wheels, truly turned and keyed to the crank shaft, must be rounded on the face so as to grip the belt when driving machinery. A high-speed governor connected direct to an equilibrium throttle valve is necessary to control the engine when belt driving.

Motion is imparted from the crank shaft to the driving rollers by a train of cast-steel gearing mounted on intermediate shafts of the best mild steel, and designed to give two speeds, the faster one being used for travelling from place to place. The driving pinions are more liable to fracture than almost any other portion of the machinery, and purchasers would do well to keep spares on hand. The authors, in view of possible trouble with broken pinion wheels, recommend keeping patterns at hand from which these parts can be cast as required at short notice. All the working parts should be covered in with wrought-iron guards. To withstand the rough usage that steam rollers occasionally experience when crossing gutters, &c., particularly strong axles are required. In this respect we, after experience of broken axles, are inclined to the belief that somewhat heavier ones than are usually provided would be advantageous in engines intended for colonial use, notwithstanding the fact that powerful screw friction brakes are fitted to enable the motion of the engine to be arrested when danger is imminent.

When a Morrison scarifier is used, it is attached generally to the right wheel, and the breaking-up of a hard road crust stresses the axle arm very severely, causing crystallisation of the steel and consequent failure. If it is intended to use such a scarifier, the arm to which it is to be attached should be of extra diameter, say not less than 5 in. for a 10-ton roller. When breaking up a hard road, it is advisable to work with a decreased number of tines, so as not to stress the axle too heavily, and in all cases great care must be taken not to cause breakages by suddenly striking fire-plug boxes, pitchers round manholes, walls of gully pits or like obstructions.

Rollers not made for scarifiers in the first instance may be fitted with one arm of increased diameter by boring out the hub to take the larger shaft and shrinking on two wrought-iron bands, with lugs, to admit of their being attached by bolts passing between the spokes.

To enable the roller to haul itself up steep inclines or out of difficult places, a winding drum can be fitted to the hind axle. Winding drums are rarely fitted unless specially ordered, but are useful additions where the engine is likely to bog in soft places. Rollers are invariably fitted with a draw-bar and pin for haulage purposes. The pull is better taken from the hind axle bearings, not from the tanks, which might thus be sufficiently strained to cause leaks. The wheels or rollers are best made with cast-iron bosses, with gunmetal bushes and wrought-iron spokes, crossed as shown in the illustrations, and bolted to cast-iron rims; they must be fitted with spring scrapers to remove any mud that accumulates on their faces. A set of tires wears out by the time about 70,000 cubic yards of average road metal have been rolled, and the advantages of renewable as against solid rims are then very apparent. For renewals, the makers can usually supply duplicate rims for the rear or front wheels of engines of their own manufacture on being furnished with the number of the engine.

The very latest practice is to re-tire both the driving and front rollers with steel plates fitted to the worn rims, and secured by countersunk rivets. The edges of the tire are turned in a lathe after attachment, and it is found that these steel-plated rims are almost twice as durable as those of cast iron, and that there is no difficulty in securing a rigid connection. The cost of plating each wheel amounts to about £20 in England.

The rims of most makes of roller have plugged holes in which picking spikes can be inserted for breaking up the road or for use when the engine is unable to proceed in soft ground. The use of these pins for breaking up is further referred to in § 114.

111. **Differential Gear.**—In a traction engine differential motion gear enables the machine to turn sharp curves without straining the wheels or axles, and is considered essential in modern practice. In the earlier types of steam roller both hind wheels were invariably pin-driven, but in the latest prac-

tice the necessity for facilities for rapid turning with a view to saving wear and tear both on the engine and on the road surface has been recognised, and leading makers now fit their best rollers with differential gearing for the purpose.

Fig. 37 illustrates the driving arrangements with this gear as turned out by Fowler and Co.

The motion of the fly-wheel is communicated through pinion and spur wheels to the bevel wheel **A** keyed to the main axle which drives the left wheel, to which it is rigidly connected by a pin. The bevel wheel **B** is bolted to the boss **C** of the right wheel. When the roller is travelling in a straight line, i.e., when the hind or driving wheels are revolving at the same speed, the pinions **D**, engaging the bevel wheels **A** and **B**, do not revolve, but act as so many driving pins. When the engine is turning a corner the wheels move at unequal rates, and the pinions **D** revolve and allow the wheels to turn at different speeds. The revolution of the pinions **D** allows each wheel to turn independently of the other, thus preventing strains. Only when travelling over soft ground or up or down steep hills should the differential gear be locked by inserting the right-hand driving pin.

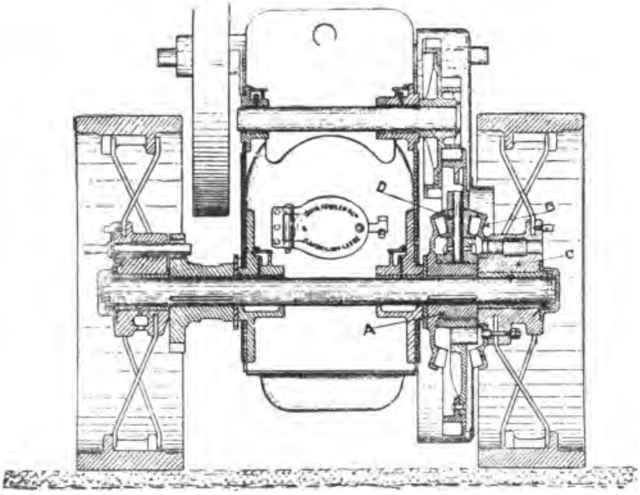


Fig. 37.
Fowler's Differential Gear for Steam Rollers.

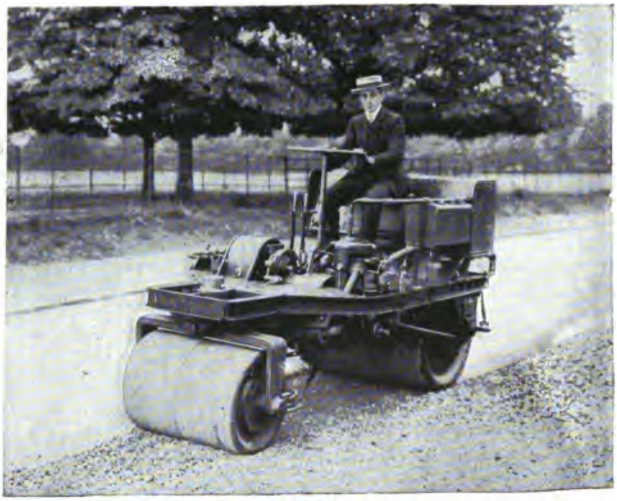


Fig. 39.

Motor Roller, by Barford & Perkins.

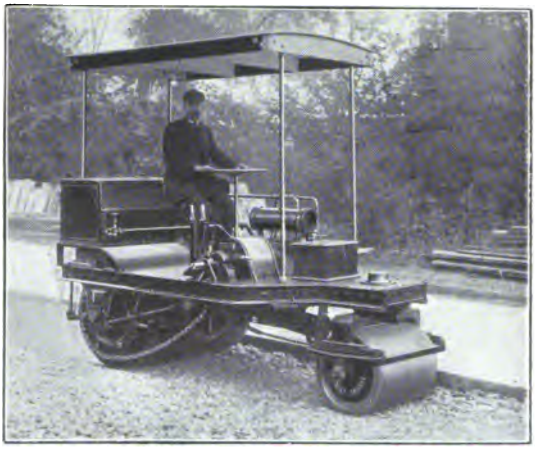


Fig. 40.

Water Ballast Motor Roller, with Fixed Pattern Hood.

To face p. 115.

Spring mountings have lately been introduced by both Fowler and Marshall, to obviate jar and vibration where a rigid roller would be a nuisance. In country districts where long journeys have to be undertaken at fast speed, spring mounting saves a good deal of time, and reduces vibration to a minimum. In addition to the parts already mentioned, the outfit should comprise firing tools, tube brush, set of spanners, hammer, caulking tools, lamps, oil can, spare gauge glasses, and fusible plugs.

112. **Motor Rollers.**—The latest development in rollers is a tendency towards the replacement of boilers and steam cylinders by oil engines.

Figs. 39 and 40 show types of water ballast motor rollers introduced in 1905 by Messrs. Barford and Perkins, of Peterborough, England, and made in eight sizes, the makers claiming the following results:—Their E size, Figs. 39 and 40, which is suitable for use on roads and streets, weighs 5 tons when empty, and 5¾ tons when full. It runs on rather less than half a gallon of petrol per hour. The weight on the front cylinder is 25 cwt., full or empty, and the maximum load on the main roller, which is 4 ft. wide, is about 2 cwt. per inch of width. A feature of special utility is the provision, when required, of an interchangeable main cylinder of a light pattern, so that a roller weighing 5¾ tons for roads, and about 3¼ tons for grass and pavement works, is obtainable in one implement. The price of Type E, with scrapers for both cylinders, powerful brake and driving pulley, is £310 in England, and that of the extra cylinder £30. Type C, for use on paths and grass, weighs 3 tons empty, and 3½ tons full, and consumes one-third of a gallon of oil per hour. The main roller is 3 ft. 6 in. wide, and the total cost £210 at Peterborough. The motors are water-cooled by automatic circulation through tanks placed over the hind roller. A friction clutch on the motor spindle allows the engine to run free for starting, and when in gear can be instantly released. Two speeds, one mile and three miles per hour, either backward or forward, are provided. When running on the slow speed, inclines of 1 in 7 can be negotiated. A pulley can be fitted to the engine for belt driving other machinery, including pumps, circular saws, chaffcutters, &c.

In America the Austin-Western Company, of Chicago, are turning out motor rollers in four sizes, ranging from 7 to 15 tons (of 2000 lbs.) in weight. Their 12-ton rollers, shown in Fig. 41, are fitted with 25-h.p. engines, developing a maximum speed of about four miles per hour. A double-speed gear is provided, and, in addition, the speed of the motor can be varied 50 per cent. by a device attached to the generator. The cylinders are cooled by oil circulation, so that no water whatever is required for their operation. Gasoline or denaturised alcohol can be used, and the tanks have a capacity sufficient for about two days' ordinary work. Friction clutches are used, and by a single lever the starting, stopping, and reversing motions are controlled from the cab. Apart from the engine, the roller is similar in design and arrangement to the ordinary steam roller, and can be used for hauling a scarifier, road machine, wagons, portable crusher, or for driving a rock-breaker or other machine. Many advantages are claimed for these new engines, and they are expected to prove particularly useful in districts where fuel and water are scarce. The time occupied, and the fuel wasted, in getting up steam are saved, and the machine can be driven by any intelligent man after a few days' training.

113. **Horse Rollers.**—Horse rollers are useful for light rolling, such as on earth formations and footpaths and for consolidating the road bed before any metal is laid.

The most convenient horse rollers now on the market are those of the reversible type, illustrated in Fig. 42, in which the pole is attached, not to the roller direct, but to a truck, which is fastened to the steel frame by means of an automatic coupling. When it is desired to reverse the motion of the roller, the coupling is released and the horses yoked to the other end of the machine. The machine illustrated is made by the American Road Machine Company, of Pennsylvania, U.S.A. Rollers which must be turned about should never be used. The best reversible horse rollers are constructed of steel throughout in sizes of 2½ to 5½ tons (of 2000 lbs.), and every roller is fitted with two weight boxes, each of which will hold up to 1 ton of pig iron, enabling the total weight to be increased by as much as 2 tons. The roller wheels should be

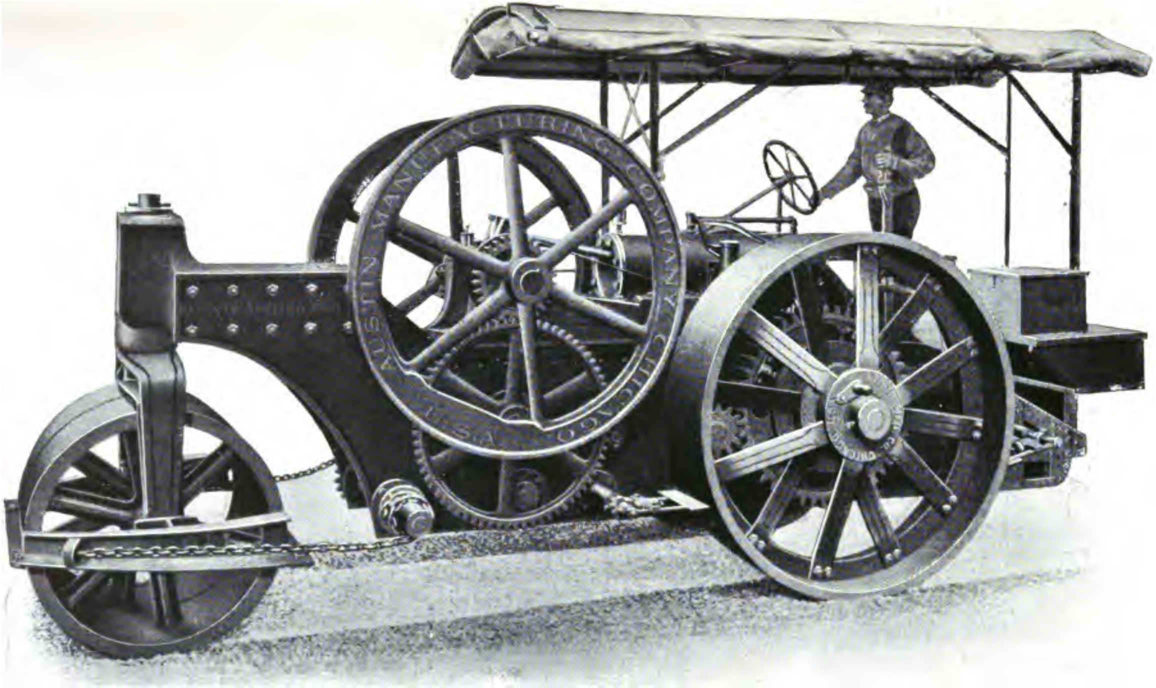


Fig. 41.—American Motor Roller.

To face p. 116.

about 5 ft. in diameter and in two sections, each revolving independently of the other on a steel axle about 4 in. in diameter. Several types of reversible rollers are obtainable, the cheapest being made in cast iron, with smaller diameter rollers and a ballast box above. The weight per lineal inch of horse rollers is too small for effective work on a metalled road. For instance, in the 5½-ton roller, weighted to 7½ tons (of 2000 lbs.), the pressure is only 255 lbs. per lineal inch, as against 450 lbs. in a 10-ton steam roller.

The cost of operating steam and horse rollers, and the amount of work that may be performed by each, is discussed in 186.

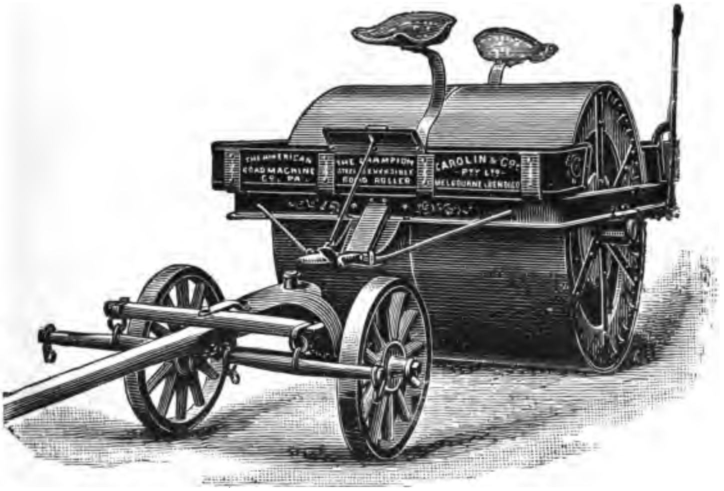

THE AMERICAN ROAD MACHINE CO. PA.
THE CHAMPION STEEL REVERSIBLE ROAD ROLLER
CAROLIN & CO. PTY LTD. MELBOURNE & BENDIGO

Fig. 42
Reversible Horse Roller.

114. Road Scarifiers.—Horse-drawn scarifiers have been tried in England and France with but little success. When steam rollers came into use the breaking-up of road surfaces was, and sometimes is still, accomplished by picking spikes attached to the driving rollers. As might be expected, the use of these appliances racks the engine severely, and shortens its life considerably. The use of picking spikes for such a purpose is condemned, though they should be carried with every roller for use when the wheels commence to skid on slippery ground.

115. Modern Scarifiers.—Mechanical scarifiers as now manufactured are either attached to or drawn by steam rollers or traction engines. Permanently attached scarifiers are preferred where steam rollers are used. Those of the second class are specially useful where rollers are not available, but where traction engines can be hired at reasonable rates, the utility and economy of scarifiers is undoubted, as will be seen from the following descriptions of some of the best-known implements on the market, and the results to be obtained by their use. The advantages of scarifying are fully discussed in Chapter X., but it may be mentioned here that one of their principal uses is in the reshaping of roads on which there is abundance of metal, merely in need of reforming and rerolling.

116. Rutty's Scarifier.—In 1884, probably the first satisfactory road scarifier drawn by chains attached to either a steam roller or a traction engine was patented by Rutty. This machine consists of a heavy cast-iron trolley, to which are attached inclined scarifying teeth or tines, capable of breaking up macadam to a depth of from 2 to 4 in. Fig. 43 shows a sketch of one type of this very useful scarifier, arranged to work on both the forward and backward motion, as manufactured with two sets of four tines. The total weight is about 2 tons.

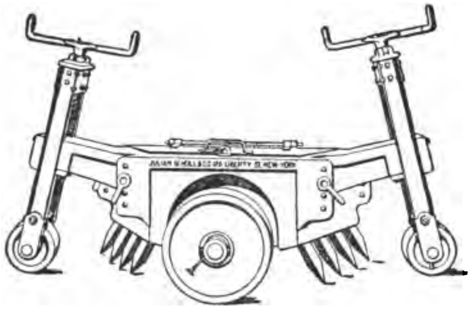


Fig. 43

Porcupine Scarifier—Rutty Type

117. Henderson's Road-breaker is illustrated in Fig. 34. It will be seen that the triangular frame, attached by a drawbar to the tender of an engine weighing at least 10 tons, is carried on three wheels. The nine drills or perforating teeth, covering a width of 6 ft., are operated through gearing by a belt working off the fly-wheel of the roller. Under working conditions from four to six tines are in use at one time, depending on the hardness of the surface. The scarifier weighs about 2½ tons, and works in one direction only, and it is necessary to run the engine, with scarifier still connected, backwards before a fresh cut is commenced. The depth of cut is adjusted by operating the two side screws shown in the figure.

118. Bomford and Marshall's Scarifiers.—The Bomford scarifier, manufactured by Fowler and Co., and shown in Fig. 33, is held to its work by a powerful spring, and is coupled directly to the main axle of the engine by a spring draw rod. It is claimed that all jar and vibration are taken by the implement itself without any loss of efficiency, and that no

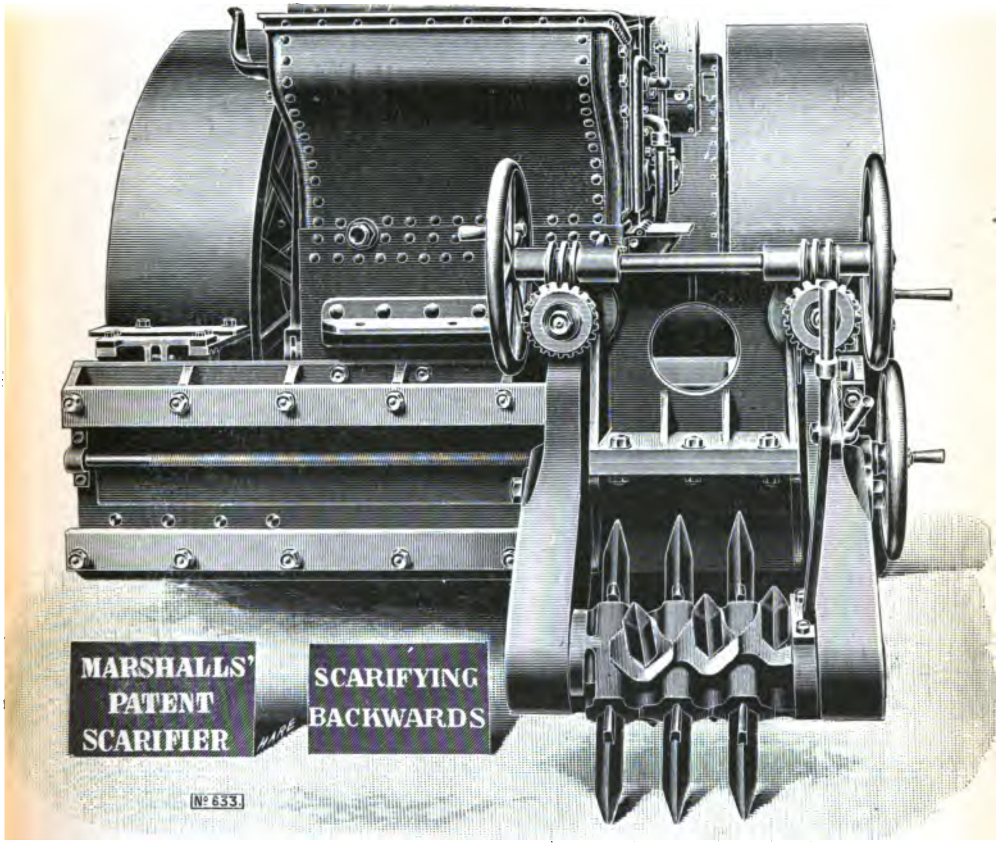


Fig. 43a.

Marshall's Scarifier, attached to Steam Roller.

strains are thrown on the boiler or tank. The scarifier works on the forward movement only, but we do not consider this much disadvantage. Its adjustment is under the control of the driver by means of levers. The tines are of square bar steel, and pointed at both ends, so that they may be reversed when worn, broken, or bent.

Marshall's scarifier, shown in Fig. 43a, works on a traversing motion, and operates either backward or forward. It possesses the unique advantage of being capable of scarifying up to the gutter on either side of the road, without the roller being turned round.

119. **Morrison's Scarifier.**—This machine, already referred to in § 110, is rigidly attached to the main axle and tender of the roller. There are two sets of three tines, spaced 6 in. apart, and mounted in a rocking block, arranged so that either may be put into action with equal facility, whether the roller is steaming forward or backwards. The depth of cut is regulated by raising and lowering the tool-holder by means of a rack and pinion and worm gearing, operated by an attendant. When cutting 4 in. deep the surface is loosened to a width of 18 in. Our experience has led us to utilise the scarifier on the forward stroke only, even though time is lost in running backwards before commencing a fresh cut. The fact that the loosened material is immediately recompressed by the right hand rear roller when scarifying backwards is a serious disadvantage. To ensure equal compression, and consequently a smooth road, no one portion of the loosened surface must be more compact than another. The scarified surface should be raked into shape before a coat of metal is applied, but the consolidating effect of even one passage of the roller wheel cannot be wholly eliminated. Attention to apparently trifling matters of this description makes all the difference between good roads and those of poor quality.

120. **Cost of Scarifying.**—We have found that scarifiers attached to rollers weighing at least 10 tons are capable of loosening about 3½ chains of road 12 ft. wide in an hour, working on the forward stroke only, provided that interruptions are not unduly numerous. It is generally safe to estimate on 300 sq. yds. per hour. Allowing for unavoidable

delays in travelling, firing, taking in water, &c., the actual working time will seldom exceed six hours per day, so that the loosening of 1800 sq. yds. 3 in. deep may be counted on as an average day's work. The running charges per day for the roller alone are given in § 185 at 32s. 3d., to which must be added an allowance of 1s. 9d. for sharpening tines, or a total of 34s. On this basis the cost works out at under ¼d. per sq. yd.

121. **Cost of Hand Picking.**—A labourer cannot loosen more than about 20 sq. yds. of hard road surface in eight hours, at a cost, allowing for repairs and renewals of picks, of about 4½d. per sq. yd., or about eighteen times as much as when done by machinery. These figures are based on the assumption that the surface is not merely scored or ribbed in the ineffective manner so often noticed, but is loosened as it should be.

CHAPTER VIII.

ROAD METAL.

122. A macadamised road surface should be hard and smooth at all seasons; its initial cost, moreover, must not be excessive, and maintenance charges should be as low as possible. The realisation of these conditions depends so much upon the quality of the stone used that this important point in road construction deserves the closest study and attention. Opinons differ as to the necessity for securing very hard rock for the foundation courses of a road, but it is conceded by most that only the best material obtainable at reasonable cost should be employed in the surface or wearing coat. On this subject generally it may be stated that no hard and fast rule can be laid down, as circumstances vary within such wide limits. As in all other engineering works, the greatest economy is attained by a thorough investigation of the question, with due regard to local conditions, somewhat on the lines indicated in Chapter II. In most of the States local government laws confer on municipal officers rights to enter lands and remove materials required for road construction purposes, provided that the owner is duly compensated. Cases have been known where such powers have not been exercised, probably through ignorance of the law, and much needless expenditure for the transport of materials over long distances incurred in consequence. In this chapter the requisite qualities, distribution, and preparation of road metals are discussed, approved methods of construction and maintenance being dealt with later on.

123. **Qualifications of Suitable Metals.**—The forces operating to destroy road surfaces will be considered in detail in §§ 191 and 192. The essential physical properties of stone required to resist these forces are given below; serious defect in any one of these is generally sufficient justification for the disqualification of what might otherwise be an excellent road metal.

(a) **Hardness,** or the property enabling stone to resist abrasion by wheels and horses' feet, is highly important. For very lightly-trafficked roads the hardest rock is not always the best, because the production of rock dust may be insufficient to replace binding material blown or washed away, with the result that the surface is liable to break up.

(b) **Toughness,** by which is meant the power to resist fracture under sharp blows such as are occasioned by wheel tires, is equally essential. Rocks, such as quartz and flint, though sufficiently hard, are deficient in toughness, and consequently too brittle to withstand heavy traffic. A knowledge of the resistance of rocks to direct crushing, though valuable in dealing with building stones, is quite useless from a road-maker's point of view.

(c) **Character of Fracture** is a more important consideration than is generally believed. Rocks such as diabase and basalt, possessing no true cleavage, can be readily broken to a fairly cuboidal shape, and are, apart from other considerations, much more valuable as road metals than those of a laminated structure, such as schists.

(d) **Chemical Durability** when exposed to the weather is essential, and the stone must in addition be sufficiently uniform in structure to wear evenly. Shales and slates are good examples of rocks useless for heavy traffic, on account of their tendency to crumble when exposed.

(e) **Cementing Power** in rock dust is a decidedly useful qualification for material intended to be introduced into the wearing coat as a binder. Something more than high cementing value is, however, required in the actual road metal; for instance, most shales and slates, though highly cementitious, would be condemned for the purpose. Igneous rocks are generally low in cementing properties, though they produce the best road metals. Elaborate tests of the cementing value of stones have been made in America, but elsewhere little importance is attached to tests of this nature, which indicate that many decidedly inferior rocks are highly cementitious, and vice versa. While it would be unwise to select an inferior dust-producing rock on account of its binding powers, the fact that roads are particularly liable to break up in dry climates should not be lost sight of.

124.—Characteristics and Distribution of Rocks.—Throughout the coastal regions of the Australian continent, rocks suitable for road construction are fairly well distributed. The plains of the interior are, however, for the most part but poorly supplied in this respect by occasional outcrops of hard intrusive or weak sedimentary rocks. Quite considerable tracts are destitute of stone of any kind, and the probabilities are that in such places nothing better than burnt clay will ever be available for road works.

Reference to geological maps will show that igneous rocks, providing the best road metal, are found over a considerable area of Australasia. They comprise a variety of basalts, granites, porphyries, &c., some of which merge so gradually from one into the other that it is very often impossible to define the division with precision. For this reason, as well as on account of an unfortunate diversity in nomenclature, the subject of road stones is best treated in a general manner.

125. Plutonic and Intrusive Rocks.—Under this broad heading are grouped all those igneous rocks that are believed to have been formed and consolidated beneath the surface of the earth. Rocks thus formed vary in composition, but are invariably crystalline in character, the development of the crystals depending largely on the rate at which cooling took place. The more important rocks suitable for road building, representative of this group, are briefly discussed below:—

Granites.—Granite occupies the lowest stratigraphical position, and in Australia, as in most other parts of the world, constitutes the rock foundation of the earth's crust. Outcrops of this rock are the result of the denudation of once superincumbent strata. The suitability of granite as a road metal depends largely upon its texture, that is, upon the grain of the crystalline structure. Granites vary greatly in texture, from coarse to finely crystalline. The coarser the crystals the weaker the stone, on account of the natural cleavages which

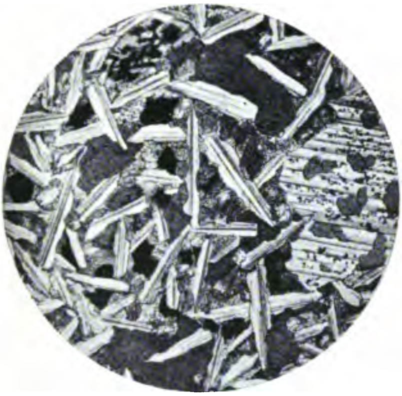


Fig. 44.

Photomicrograph of a Granite Section.

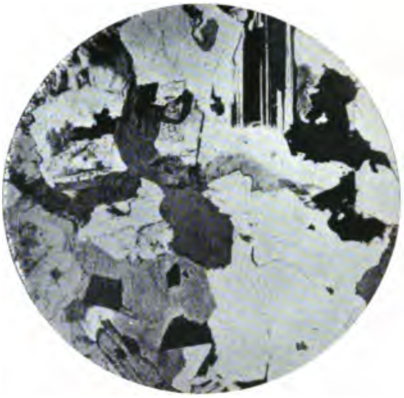


Fig. 44a.

Photomicograph of a Limestone Section.

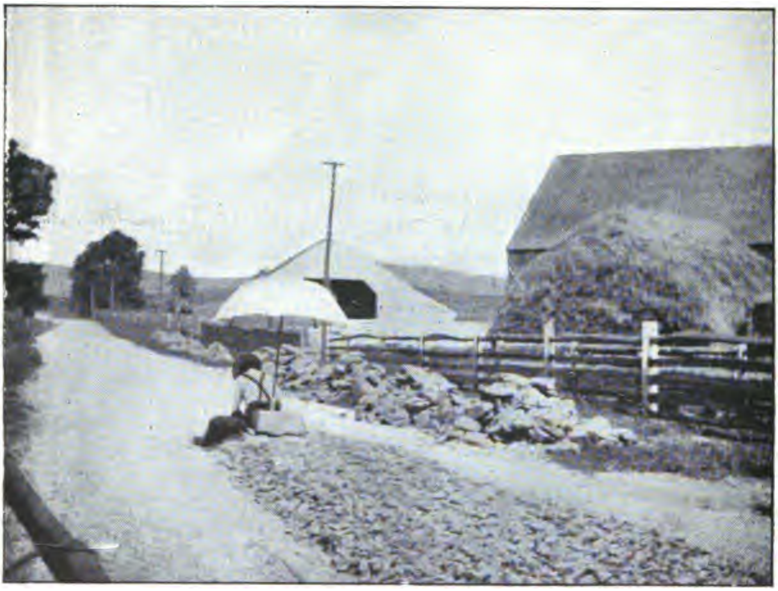


Fig. 45.

Survival of Early Road Methods.

To face p. 125.

allow it to break up and crumble. *Fig. 44 shows a photomicrograph of a granite section in which the interlocked structure is clearly shown. Granites, on the whole, are not in the first rank among road metals owing to their brittleness, and to the great diversity in hardness between the quartz and felspar constituents on the one hand and mica, the third component, on the other. Granites comparatively free from mica are naturally more durable than those rich in that mineral. The degree of freshness of the mineral constituents in granite requires careful investigation. The felspar is sometimes much decomposed, and so liable to turn to slush in wet weather as to render the rock quite unsuitable for road or even footpath work. Syenite granite is distinguished from true granite by the absence or small amount of quartz present, and consists essentially of felspar and hornblende. It is usually tougher and more durable than ordinary granite, though by no means widely distributed. The largest tract of granite country is found in Western Australia, but the rock is fairly widely distributed in all the other States, with the exception of Tasmania, which, fortunately, is well provided with other suitable stones. Granite does not occur extensively in New Zealand.

Porphyries.—Owing to the micro-crystalline texture of the ground mass of quartz and felspar in which large detached crystals are embedded, there is an absence of the natural cleavage planes so pronounced in granites, which, however, consist of the same minerals, but in larger grains. Although fine-grained rocks are generally tougher than those of coarse texture, porphyritic rocks are generally quite sound enough for practical purposes, provided that the matrix holding the larger crystals is dense and but little decomposed. Porphyries are not widely distributed in Australasia, though a valuable rock, so classed, is found in the New England district of New South Wales, and in other localities.

Diabase.—The name *trap* is by some loosely applied to rocks of this class, akin, and very similar in appearance to the finer grained granites; by others they are vaguely termed greenstones. Rocks of this class are, owing to their microcystalline texture, with the minerals composing them closely interlocked, particularly tough and hard; though difficult to break, they produce better road metal than does basalt. Extensive outcrops of this rock occur in Tasmania, the quarries in the vicinity of Launceston furnishing good examples of first-class road metal. In Victoria it occurs, among other localities, at Mt. Macedon, Mt. Dandenong, and near Dookie. In Johannesburg, South Africa, diabase has been used for macadamising the principal streets, but the rock is considered too tough for the rock crushers. With modern machinery it is an extremly hard stone that cannot be broken satisfactorily; objections to a stone on account of its hardness and toughness are not always well founded.

---

* Reproduced from Circular 29, Office of Road Inquiry, U.S.A.

126. Volcanic Rocks.—In this group are included rocks originally erupted by volcanic action. Crystallisation is to a large extent absent owing to the conditions of cooling, and the rocks are more or less glassy in texture. The principal rocks of this class met with in Australasia are the older and newer basalts. *Basalts.*—For road purposes the newer basalt is far more important than that of earlier origin, which is generally decomposed. Basalts, like all other rocks, vary in quality, but the more compact bluish-grey kinds, popularly termed "bluestones," provide high quality road metal, surpassed only by certain of the plutonic rocks mentioned above, notably diabase. Where basalt can be carted straight from the rock-breakers to the streets, as in the City of Melbourne, it is so much cheaper than harder stone, rail borne, would be, that it is not at all likely to be superseded by the latter. In the case of Melbourne suburban councils that must rail their metal, however, it is by no means certain that it would not be better to bring harder diabase metal from Ferntree Gully, at the foot of Mt. Dandenong. For example, metal is just now in Victoria carried 16 miles for municipalities for 2s. 1d. per ton (23 cubic ft.), while the freight for 31 miles would be 2s. 6d. per ton, or an increase of, say, 6d. per cubic yard. The harder rock would have to be broken smaller than the basalt, to say not larger than 2-in. gauge, but under very heavy traffic the former would undoubtedly be far more durable, and probably more economical in the long run. These facts are mentioned as an example of the necessity for close investigation before the opening up of quarries is decided upon. A defect to be avoided in the selection of basalt is an excess of amygdaloids coated with carbonate of lime, and popularly known as "bird's-eye." Highly vesicular (honeycombed) basalt is weak, and its use should not be permitted. Basalt scoria, pumice and volcanic ash, generally stratified, are for obvious reasons quite unsuitable for road metal, though sometimes very satisfactory for footpath construction. On account of its wide distribution, basalt is without doubt the principal, though not necessarily the best, rock available for road works within the Commonwealth. Parts of New Zealand are, on the whole, rather worse supplied than many of the settled regions of Australia. An idea of the value of basalt as a road metal can be gathered from the fact that the Sydney City Council brings this rock long distances from Nepean, Kiama, and even from Melbourne. Basalt is largely used in Capetown, South Africa. The Auckland (N.Z.) metal is described by the City Engineer as only fair, being very irregular in character, and varying from close-grained to very honeycombed bluestone. Kerbing and pitchers are made from the best of this rock, while the scoriaceous boulders are employed for hand-packed rubble foundations of roads.

127. **Metamorphic Rocks.**—Under this heading are included all sedimentary rocks, the mineral character of which has been altered by long continued pressure and heat, as well as those merely hardened or indurated by the same means.

Schists afford a notable example of metamorphism by the alteration of shales into foliated rocks called schists. Quite a large area in the Middle Island of New Zealand consists of mica schists, which, owing to their laminated nature, are quite unsuited for road metal. Foliated rocks are invariably of a friable nature, and can never be regarded as satisfactory.

Metamorphic Granites, so called, are stratified rocks mostly of the Silurian era altered to assume a crystalline structure similar in appearance to granite. For road construction purposes the considerations applying to granite are mostly applicable to this stone. Quite large areas of this rock are found in Western Tasmania, N.E. Victoria, and elsewhere.

Quartzite is sandstone compacted by metamorphism into a hard dense body, and though vastly improved by the change, is generally wanting in toughness and cementing properties, and consequently rather unsuited to a dry climate.

128. Sedimentary Rocks.—Sedimentary rocks produced by the action of water on igneous rocks are generally too weak to be satisfactory, though their use is, in many places, quite unavoidable. Where igneous rocks can be obtained sedimentary rocks will seldom be preferred.

Sandstone consists of quartz grains united by cementitious material, on the nature of which depends very largely the soundness of the rock. Sandstone in which the grains are united by a siliceous paste is very much stronger than one in which the grains are bound by calcareous or argillaceous matter. In fact, sandstones of the latter class have practically no value in road construction, except in the foundation, as they rapidly break down into incoherent sand when dry, and possess but few adhesive qualities when wet. Very few of the sandstones found in Australasia, as exemplified by the Hawkesbury sandstones around Sydney, furnish suitable road metal. Experience of "blue-bar" in Johannesburg, South Africa, has proved this sandstone useless for busy thoroughfares.

Shales and Slates are unsuitable, as they rapidly break down into clayey materials when wet and turn to mud. They are used of necessity in many places, but never from choice.

Limestones are extremely variable in durability, ranging from fairly hard to very soft. They are found in all colours, and to the casual observer are often mistaken for other rocks, though they can be readily identified by noting effervescence on the application of a small quantity of hydrochloric acid. The older limestones, including those of the Silurian period, especially those indurated by heat, are the most suitable. For very heavy traffic the hardest limestone is not sufficiently durable, though for light traffic it makes a smooth and pretty hard, though somewhat dusty, road surface that binds well. Compare the structure of limestone with that of granite. For use in tar-macadam, limestone is preferred by many to the harder rocks on account of its somewhat porous nature. Bituminous limetones such as are found on the Continent have not been discovered in any appreciable quantity in this country. Should quarries of this valuable rock be opened up they would be very valuable for asphaltum pavements.

Flint, an impure form of silica, is occasionally used on road works, but, owing to its brittleness and the absence of binding properties, is not very satisfactory, especially in countries with dry summers. This rock, though standing out well in attrition tests, is particularly liable to splinter, and is severe on tires, especially those of rubber.

129. Testing Road Metals.—Up to the present our knowledge of the suitability of Australasian stones for road purposes is almost wholly based on general conclusions by observation of their behaviour under traffic. The test of actual use is undoubtedly safe and reliable if skilfully conducted, but necessitates extended observation over a series of years, during which the conditions as to traffic and climate may naturally be expected to vary. Of recent years laboratory methods have been introduced, whereby the *relative* wearing qualities of road metals can be determined with reasonable accuracy. Tests of this nature do not furnish a strictly scientific indication of the behaviour of rocks under actual traffic conditions, but are useful when a knowledge of the probable wearing capabilities of stones is desired prior to their extensive use. French engineers instituted separate tests for abrasion and impact in the year 1880, and later M. Deval arranged a combined attrition test that was introduced into America by Mr. L. W. Page, now Director of the Office of Public Roads. Mr. Page invented a further test, in which, as mentioned above, the cementing value of stone dust was ascertained by moulding it into small briquettes to be broken by impact. Investigations are proceeding, and it is expected that further interesting results will soon be published. In England valuable work has been done by Mr. E. J. Lovegrove, borough engineer and surveyor of Hornsey, who in 1906 published his results in "Attrition Tests in the Light of Petrology." Cementation experiments are not recorded in this work, and the investigations were confined to attrition tests, in which abrasion and impact tests, formerly conducted separately, are combined with a scientific study of the petrological structure of each specimen. The testing machine employed consists of three rotating cylinders of cast iron, each 11 in. internal diameter, set horizontally, and driven by bevel gearing off one countershaft. Each cylinder is fitted with three 1 in. x 1 in. angle ribs, spaced equally, and placed parallel to the axis of rotation. A sample is tested in each of the three cylinders simultaneously. The rock to be experimented upon is broken to a 2-in. gauge, and samples weighing 4 lbs. in all are tested both wet and dry. The cylinders are revolved at a speed of twenty revolutions per minute, recorded by a counter, until a total of 8000 revolutions is reached. In the wet test the stones are weighed dry, and placed in one of the cylinders with half a gallon of water, and reweighed when thoroughly dried after testing. The results of tests are expressed in the percentages by weight of the dust worn off to the weight of the unabraded sample of stone. The stones are more or less rounded during the test, and the results, even with stones of identical composition, naturally vary slightly with the number and size of the specimens. Table X. summarises the results, arranged in petrological groups, of a series of tests. The figures represent the average percentage of loss in dust (wet and dry tests) of 134 samples from quarries in the British Isles and on the Continent. More experiments are required before full definite conclusions can be drawn, but the superiority of quartz-diabases is clearly established.

TABLE X.

ATTRITION TESTS BY MR. E. J. LOVEGROVE.

PETROLOGICAL GROUPS.	Number of Stones Tested.	ATTRITION RESULTS.		
		Highest.	Lowest.	Mean. (Approx.)
Quartz—Diabases	4	2.66	5.47	3.82
Diabases, Dolerites, and Basalts	21	3.42	29.93	12.73
Porphyries and Porphyrites	14	3.71	13.50	6.7
Granitic Group	13	6.61	15 23	10
Granite	5	6.61	15.23	11
Diorite	3	7.49	9.94	9
Gabbro	3	9 08	10.74	10
Gneiss	2	8.03	8.59	8
Andesites	4	5.98	15.68	10
Hornfels	4	6.47	8.05	7.5
Sandstones and Quartzites	23	3.73	44.99	15
Quartzites	5	3.73	7.30	5.5
Flints	11	7.49	13.38	10
Pit Flints	5	7.81	10.62	9
Surface Flints	6	7.49	13.38	10.5
Limestones	11	11.13	33.89	20

There is little doubt that complete and authoritative tests of rocks obtainable in the settled districts of Australasia would be extremely valuable and instructive if systematically recorded in easily accessible form. Facilities of some sort should be available whereby tests could be made for shire and other engineers desirous of ascertaining the probable capabilities of rocks at their disposal for road construction.

130. **Quarrying.**—When opening up quarries great care must be exercised in the choice of a site. Not only must the quality of the stone be satisfactory, but the deposit must be sufficiently extensive to warrant the installation of the necessary plant. Lava flows are specially deceptive in this respect, and those which, by surface indications, appear to extend to great depths, may, when opened up, be found to overlie decomposed basalt of earlier deposition at quite shallow depths. The overburden to be removed must not be unduly deep, say not more than 5 ft., or the dead work involved in stripping greatly increases the cost of the road metal. For economy of working, the bed joints should dip towards the working face, from which it is desirable, though not always possible, that the quarried rock should be conveyed by gravity to the crushers. Where the quarry is deep below the natural surface, and the spalls have to be raised by mechanical means, cranes are most usually employed, though hoisting cableways somewhat as illustrated in Fig. 46 are more economical where the output is extensive.

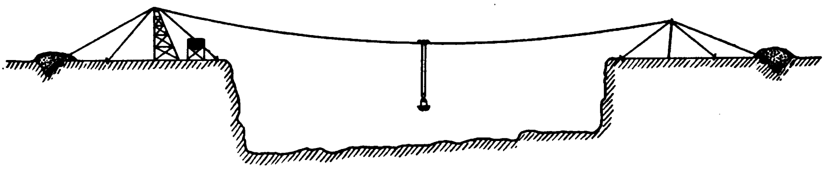


Fig 46.

Hoisting Cableway installed in a Quarry.

131. **Methods of Quarrying.**—The best road stones require to be loosened by drilling and blasting; only inferior rock can be removed by picks, gadzes, wedges, and levers. A good quarryman will invariably study the natural bedding and joint-

ing of the rock before commencing operations, and will utilise them to the utmost in his operations. In quarrying, the greatest economy is always realised when blasting is carried out on a comparatively large scale; that is to say, it pays better to spend some days, or even weeks, in preparing for quite a number of charges to be exploded simultaneously than to break down a few tons each day by shots fired singly. Quarries up to about 25 ft. deep are generally best worked in one face, as shown in Figs. 47 and 48, in which the bore holes are clearly indicated. Where hand drilling is adopted, the face must not exceed 20 ft., as the depth of the bore is limited to about 10 ft.

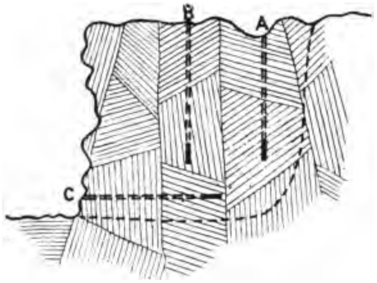


Fig. 47.
Section, Scale 20 ft. to an inch.

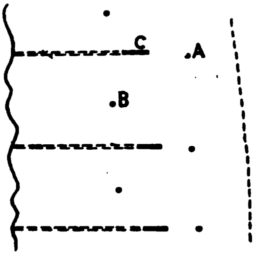


Fig. 48.
Plan, Scale 20 ft.

The probable lines of rupture are indicated by broken lines on the assumption that the charges are fired simultaneously, as they must be to ensure economy.

For depths exceeding 25 ft., where machine drills are employed, and 20 ft. with hand drills, the system of benching shown in Fig. 49 is recommended, especially when the drilling is done by hand, as the bore holes, being vertical in every case, cost not more than two-thirds of those that are horizontal or nearly so.

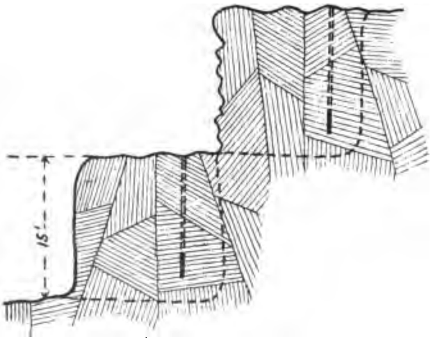


Fig. 49.
Section, Scale 30 ft. to an inch.

132. Lengths of Boreholes Required.—The holes can generally be spaced no further apart than their depth, in which case an excavation 3 ft. deep requires about 3 lineal ft. of hole per cubic yd.; if the holes could be spaced 9 ft. apart, 4 in. per cubic yd. is all that would be required. It will thus be seen that drilling, which constitutes such a large proportion of the total cost, increases very rapidly as the depth to be loosened decreases. The greatest economy is nearly always secured when the holes are 14 to 16 ft. deep. In the very toughest rocks the boreholes can rarely be spaced more than 8 ft. apart (**A** to **B** in Fig. 48) no matter what their depths, in which case it is necessary to allow for at least 5 in. of drilling for every cubic yard of solid rock to be moved. Conditions vary so widely that it is impossible to lay down any rigid rule, but the following figures are approximately correct for basalt and granite when the distance apart of the boreholes is equal to their depth:—

Distance apart of Holes.	Length of Hole to be Drilled per cubic yard of solid Rock.
3 feet	3 feet 0 inch
4 ,,	2 ,, 0 ,,
6 ,,	0 ,, 10 ,,
8 ,,	0 ,, 6 ,,
10 ,,	0 ,, 5 ,,
12 ,,	0 ,, 4 ,,
14 ,,	0 ,, 3½ ,,

In Figs. 47 and 48 it will be noted that the borehole **B** is placed so that the distance from the centre of the charge is about equal to its depth below the surface, on the assumption that the resistances horizontally and vertically are about equal. With basalt and most granites it is a good rule to space the vertical boreholes the same distance apart, as shown in Fig. 48. This spacing determines the position of the inner row of holes. The effect of the blast will be to dislodge the mass extending 3 to 4 ft. inwards from the line of charges.

133. Hand Drilling.—In small quarries hand drilling is generally adopted. Single hand drilling is performed by one man in a sitting posture with a hammer weighing 4 to 5 lbs., but is not so economical as the double-hand method, generally performed by three men, one holding and turning the drill, and two striking with hammers up to 10 lbs. in weight. The borehole should be kept well supplied with water as the work proceeds. Holes can be put down by the double-hand method up to a depth of from 6 to 8 ft. For greater depths, up to about 10 ft., a churn drill, lifted and dropped by two men, must be used. The costs per foot of hand drilling vertical 1½-in. holes under Australasian conditions (including sharpening of drills, for which about 3d. per ft. must be allowed), and time lost in cleaning out holes, are about as under:—

	s.	d.	
Basalt	2	1	per ft. in depth.
Hard limestone	1	6	„ „
Hard granite and diabase ..	3	2	„ „

134. **Machine Drilling.**—There is no doubt that machine drills are a great advance upon the old method; with them the cost is only about two-fifths of that given above for hand boring, provided that the work to be done is sufficiently constant to warrant the purchase of the tools. Rock drills, as used in quarries, are invariably mounted on weighted tripods, which permit of their adjustment to any angle, and are driven by compressed air or steam as desired.

Compressed air is better, especially where the engine is situated some distance from the face. The advantage of steam in certain cases lies in the facility with which the power can be conveyed to the drill directly from the boiler of a traction engine or roller without the intervention of an air compressor. For this reason steam driving is popular in the smaller quarries. Where electric current is available it is better applied to run motor-driven air compressors than to operate the drills directly. Air compressors can, of course, be driven by oil or gas engines if desired.

The sizes of drills are denoted by the diameters of their air or steam cylinders; 2¼-in. is a very small drill, while 3¼-in. is a common size, and one that will bore a hole to a depth of, say, 14 ft., commencing at 2½ in. and finishing 1¾ in. diameter.

135. **Explosives.**—The harder the rock the quicker in effect should the explosive be; that is to say, it must exercise great shattering force. Dynamite, blasting gelatine, gelignite, rackarock, and roburite are the most commonly used of the higher explosives.

Dynamite is made of several strengths for various purposes. No. 1 contains 75 per cent., No. 2 about 50 per cent., and No. 3 about 30 per cent. of nitro-glycerine, absorbed in a diatomaceous earth; the powers are about proportional to the nitro-glycerine contained. Dynamite should be kept in a warm, dry atmosphere. It works best at about 75 deg. Fahr. In cold weather it should be heated to this temperature in a tin vessel partly submerged in water at temperature of about 100 deg. Never allow the workmen to heat it in a frying pan or before a fire, as it is an exceedingly dangerous practice. Dynamite is particularly rapid in action, and possesses great shattering force.

Blasting Gelatine.—No. 1 blasting gelatine contains about 94 per cent. of nitro-glycerine, and though slower in its action than No. 1 dynamite, is nearly 50 per cent. more powerful. For dislodging rock in masses suitable for kerbing and cut stone work generally blasting gelatine is specially adapted. For quarrying road stone, which for economy should be well shattered to save sledging before crushing, dynamite is often preferred.

Gelignite is a very popular and effective explosive, containing about 63 per cent. of nitro-glycerine. Gelignite, like blasting gelatine, is somewhat slower in its action than dynamite, but nevertheless is thoroughly reliable. The cost ranges from 1s. to 1s. 3d. per lb., depending on the quantity purchased and the distance from a seaport.

Rackarock is composed of compressed cartridges of chlorate of potash impregnated shortly before use with nitrobenzole or dead oils. When kept separate the cartridges and the oil are non-explosive, and quite harmless. Even when prepared for use rackarock is comparatively safe to handle, as it merely burns away when thrown into a fire. When properly confined its explosive strength is about equal to No. 1 dynamite.

Roburite consists of chlorinated dinintro-benzol and ammonium nitrate, which are harmless till mixed, after which they have the appearance of brown sugar. Its explosive strength is about the same as No. 1 dynamite or rackarock, and it emits no noxious gases when properly exploded. All these are sold in cartridges, which before insertion into the borehole are slit with a knife to permit of the explosive filling the chamber as they are pressed into place with a wooden rod, it being remembered that the diameter of the hole must be a little larger than that of the cartridge. As many cartridges as are necessary are dropped into the hole and pressed home. The paper of the last one, called the primer, is not slit, but a hole is made in its end with a wooden pin for the reception of the detonator. The detonator is a hollow copper cylinder, about ¼ in. diameter and 1 in. to over 2 in. long, partly filled with fulminate of mercury, a deadly explosive. Detonators cost from 32s. 6d. to 35s. per 1000. The fuse is pressed, not twisted, into the detonator, which is pushed into the cartridge to about three-quarters of its depth, and the whole is secured by pinching the paper of the cartridge round the fuse with a special pair of pliers, or by two nails tied at the heads. The fuse is generally of the double tape manufacture, supplied in packages of twenty-five coils, each 24 ft. long, and costing 6d. to 9d. per coil. The borehole is then tamped with dry earth or fine sand, lightly pressed down to exclude air. Tamping with water is not recommended. The greatest care must be taken in laying the charges, and the work should be entrusted to none but experienced workmen. It should be remembered that the detonators are more dangerous to handle than the actual explosives.

When soft stone is to be dislodged slower-acting explosives of great heaving power give better results, and the stronger grades are suitable only for chambering or "bulling" the bottom of the drill hole by small charges into a bulb-like shape to hold the charge, which, if of blasting powder, is poured in as gunpowder would be.

Blasting powder can be fired directly with an ordinary fuse inserted into the mass, or with more instant effect by a detonator as described above. The tamping should be of hard material, driven well home, no angular pieces being permitted that might cut the fuse. A copper rod, or an iron one tipped with copper, must always be used when tamping powder. Blasting powder possesses about one-sixth the explosive power of No. 1 dynamite, and costs from 6d. to 7d. per lb.

136. Blasting Machines.—When two or more charges are to be exploded simultaneously the firing must be done with the aid of electric detonator fuses, specially prepared, and placed in the circuit of one of the numerous blasting machines, the largest of which now on the market will fire up to about twenty-five shots at once. The electric detonator fuse is inserted in the primer as described above, except that it is completely covered by the explosive. Bare copper wire can be used in joining up with the machine, but insulated wire is better in damp places. Misfires rarely occur with electric exploders; hangfires are impossible.

137. Quantity of Explosive Required.—The weight of explosive required per cubic yard of rock dislodged varies with its composition and the texture of the rock, as well as the skill with which the charges are placed and laid. Then, again, the number of shots to be fired at once and the depth of the charges vary greatly. The most reliable method by which the charge can be determined in the first place is to calculate the approximate content of rock to be loosened by preparing diagrams such as in Figs. 47, 48, and 49, and then to estimate the weight of explosive to be allowed for each cubic yard. When masses of about 500 cubic yds. or more are to be dislodged in one blast each pound of No. 1 dynamite may be relied upon to throw 5½ to 6½ cubic yds., measured in the solid, of hard basalt. When smaller volumes are to be moved by three or four charges in boreholes 12 or 14 ft. deep, fired by an electric exploder, allow 4 to 5 cubic yds. for every pound of that explosive. When the shots are fired singly in 10-ft. boreholes do not rely on more than about two-thirds of the last-mentioned figures. If gelignite is used, deduct about one-fifth, and for No. 2 dynamite deduct about one-third. Remember that in all cases the figures refer to stone measured solid, not when broken up into road metal. There are so many conditions, such as the jointing and bedding, to be considered that the figures are only to be regarded as approximations to be varied as the result of actual experience in any particular quarry. See § 321 for further information on blasting out side cuttings. The cost of explosives varies from time to time, and depends so much on the magnitude of the order that special quotations must be sought from suppliers.

138. Volume of Metal and Screenings Produced.—The increase in volume or swelling of rock upon breaking up is as under:—

Voids	33 %	35 %	40 %	42½ %	45 %	50 %
Cubic yds. measured loose produced by 1 cubic yd. solid ...	1.48	1.54	1.67	1.74	1.82	2.00

In actual practice the percentage of voids present in road metal depends upon the uniformity with which the rock has been broken and the extent of subsequent shaking down or consolidation effected; if the metal has been screened, the voids depend upon the percentage of comparatively fine stuff left in.

Rounded fragments pack more closely than angular ones; perfectly spherical balls of uniform size can be hand packed so that the voids do not exceed 26 per cent. If the sizes are mixed the voids can, obviously, be reduced. The voids in pit sand range from about 35 to 40 per cent. Broken stone of hard quality comes from the crusher with about 35 per cent. of voids; when screened and sorted into several sizes the voids in each size average about 45 per cent., but shake down on a journey by rail, or even in wagons, to about 42½ per cent. It may be generally assumed, therefore, that on an average each cubic yard of solid rock produces about 1¾ cubic yds. of broken stone. The proportion of screenings, toppings, and dust to useful road metal varies with the nature of the rock. With hard stone, such as basalt, machine-broken, about 25 per cent. of the total is too small for use on a carriageway, except perhaps as binding after a first rolling. With soft rock, such as limestone, as much as 35 per cent. of the whole will consist of chips and fine stuff. Each cubic yard of hard average rock may then be expected to produce 1.75 — 25 per cent., say, 1 1-3 cubic yds. of useful road metal, and the softer rocks about 1.75 — 35 per cent., say, 1 1-7 cubic yds.

139. Cost of Quarrying.—Unless the conditions are fully stated, data relative to the costs of quarrying are valueless. What, for instance, is the value of figures that do not explain whether the volume of rock removed has been measured in the solid or loose after crushing? Then, again, there must be no misunderstanding as to whether the figures apply to the whole of the product, inclusive of screenings from subsequent crushing operations, or merely to the sizes of stone suitable for road making after the fine stuff has been removed. More often than not screenings and dust are useful for concrete, tarpaving, and other works, or for binding the road surface, and in most cases we think they should fairly be included in the records of useful stone produced. In England road metal is usually sold by weight. Each system has its advantages, but cubic content can generally be more easily arrived at than weight, though perhaps not quite so accurately. In the following tables, summarising the cost of quarrying, we have arranged the data as for four conditions so as to facilitate comparisons, and to show clearly the importance of stating the exact circumstances under which the figures are obtained.

Table XI. shows the cost of quarrying basalt on a fairly small scale where the drilling is effected by hand. Interest on plant required for quarrying is inconsiderable, and can be ignored. The costs here given do not include the expense of transporting the rock from the quarry to the crusher.

TABLE XI.

Average cost of quarrying basalt, and breaking down for feeding a 16-inch x 9-inch crusher, drilling by hand, shots fired singly, high-grade explosives used.

ITEM.	COST IN PENCE.			
	Per Ton, about 12.6 cubic ft.	Per c. yd. in solid Sp. Gr. = 2.85.	Per c. yd. of Metal and Screenings loose; 1 c. yd. solid = 1¾ c. yd. loose.	Per c. yd. of Metal after Screenings removed; 1 c.yd. solid = 1⅓ c. yd. loose.
Stripping surface (very variable)	1.4	3.0	1.7	2.2
Drilling 1½-inch holes	5.2	11.0	6.3	8.3
Explosives (bought in small lots), detonators, fuse and labour in charging and firing ..	2.8	6.0	3.4	4.5
Sledging, or breaking down, and throwing back	4.2	9.0	5.1	6.7
Total cost	13.6	29.0	16.5	21.7

TABLE XII.

Average cost of quarrying basalt, and breaking down for feeding a 16-inch x 9-inch crusher, machine drilling, and shots fired simultaneously.

ITEM.	COST IN PENCE.			
	Per Ton, about 12.6 cubic ft.	Per c. yd. in solid Sp. Gr. = 2.85.	Per c. yd. of Metal, and Screenings loose; 1 c. yd. solid = 1¾ c yd. loose.	Per c. yd. of Metal after Screenings removed; 1 c. yd. solid = 1⅜ c. yd. loose.
Stripping surface soil (very variable)	1.4	3.0	1.7	2 2
Drilling holes 2½ inches to 1¾ inches	2.4	5.0	2.9	3.8
Explosives, detonators, fuse and labour in charging and firing	2.1	4.5	2.6	3.4
Sledging, or breaking down, and throwing back	3.3	7.0	4.0	5.3
Total cost	9.2	19.5	11.2	14.7

Comparing Tables XI. and XII., it will be noticed that drilling is very much more costly in the case of hand boring. This is due, not only to less rapid progress where manual labour is adopted, but to the fact that with shallower drill holes the length of bore per unit of mass dislodged is largely increased.

140. **Machine v. Hand Breaking.**—Until quite recently there has existed a prejudice against machine-broken metal, and there are still to be found in Australasia many advocates of breaking by hand. It is true that skilful hand breakers can produce more cuboidal stone, but the number of men expert at this class of work is dwindling, and it is only a matter of a short time before practically all road metals will be broken by machinery. One great disadvantage in hand breaking is the difficulty experienced in getting the stone broken small enough, no matter how strict the supervision. Then, again, hand-broken metal is at fault in that too large a percentage of chips is present. Neither of these defects can be present in machine-broken metal after it has passed through modern screening appliances. The only objections that can reasonably be urged against machine breaking is the tendency to produce flaky

rather than cuboidal stones, with the edges somewhat rounded and abraded. Modern crushers have, however, been greatly improved, and metal turned out by them is quite as good as can be secured by hand breaking, unless the hand-broken metal is screened. See § 169 and Fig. 75. Any difference in quality is more than counterbalanced by the increased cost of the latter. The ruling rate for hand breaking basalt rock of medium quality averages about 2s. 3d. per cubic yd., measured in the heaps, and screening costs about 6d. per cubic yard extra, making a total of 2s. 9d. The cost of breaking and screening the same rock by machinery would be about 1s. per cubic yd., so that the saving, allowing an additional 6d. for extra handling, amounts to about 2s. 3d. per cubic yd.

Some years since, the authors, finding that hand-broken basalt was costing about 2s. per cubic yd. more than crushed metal, advised a municipal council that they were losing practically the whole of the money paid to the breakers, who, by the way, were not making on the average 15s. per week each. Comparative tests being desired, several contiguous experimental lengths were laid down in different parts of the municipality, and as nearly as possible under exactly the same conditions for each pair of lengths. After about one year's wear these were inspected, but the advocates of hand breaking in nearly every case failed to distinguish correctly between the different classes of metal, and some years later when the whole came to be remetalled no one could tell from the condition of the roads which was which. After this it was agreed that breaking by hand was not advisable.

141. **Stone Breakers.**—Rock-crushing plants may be either fixed or portable; their general arrangements are illustrated in Figs. 50 to 56.

At properly-equipped quarries, working full time, or nearly so, one or more stationary crushers are certainly required. In country districts, where stone is most easily obtained in the vicinity of the roads, machines of the portable type, such as shown in Fig. 56, are to be preferred, as they can be hauled about by a traction engine or steam roller, and belt driven thereby.

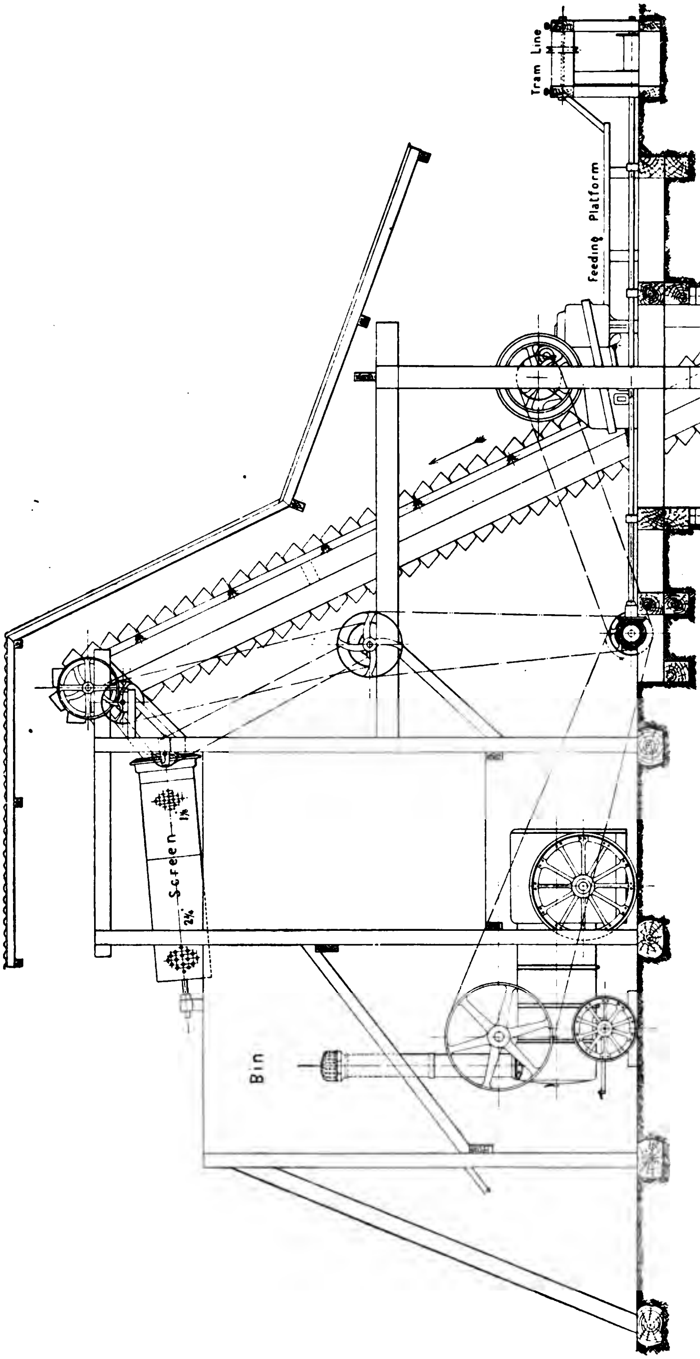


Fig. 50.—Stationary Crushing Plant on Level Ground, with Elevator, Screen, Bins, &c.

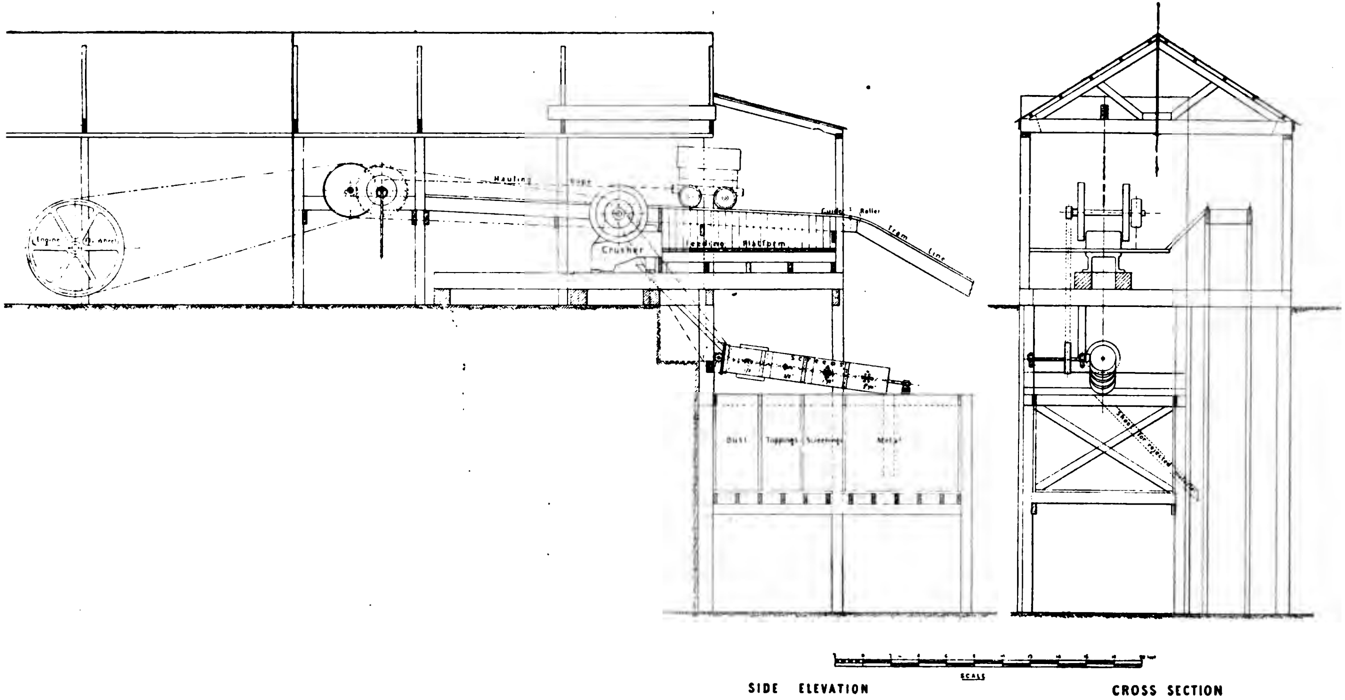


Fig. 51.
Stationary Crushing Plant on a Hillside, with Screens, Bins, &c.

Fig. 50 shows a plant on level ground driven by a portable engine where the crushed stone has to be elevated before screening. It will be seen that the broken stone drops from the crusher to the elevator, by which it is raised and again dropped into the sloping screens, which size the metal into the various hoppers, from which drays or trucks are filled through movable doors not shown in the drawing.

Fig. 51 shows a plant that has been erected in a position where advantage was taken of a natural difference in level that enabled the crushed metal to gravitate through the screens directly to the bins. By this arrangement elevation is dispensed with except for the return of stones passing through the crusher, but rejected by the screens on account of their large size. The elevator for rejects is not shown on the diagram, but is a simple arrangement that redelivers the oversized stones directly to the crusher without handling of any sort.

142. **Jaw Crushers.**—Stone-breakers are of either the reciprocating or rotary types. The general design of the former, as made by Jaques Bros., is shown in Fig. 52, and the details of the mechanism in Fig. 53. The frame is of cast iron, near one end of which is a swinging jaw holder **A**.

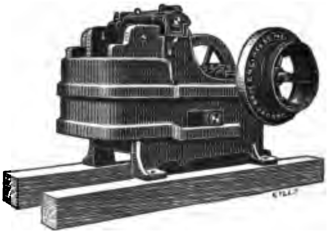


Fig. 52.

Oscillatory motion is imparted to **A** by the toggle **H** working in manganese steel seat, and operated by the cast-steel bent lever **B**, the end **C** of which is raised and lowered once during each revolution of the fly-wheel by the connecting rod **E** attached at its upper end to a crank on shaft **D**. The jaws **F** and **G** are of chilled steel, backed with strips of white metal to ensure an even bed. These jaws are not only interchangeable, but can be reversed, which is an important feature. All bearings are fitted with brasses of phosphor-bronze, generally considered superior to Babbitt's metal. The stroke of the swinging jaw-holder is varied by raising or lowering the block **L**, and the wear of the jaws and bearings is taken up by adjusting the movable blocks **J** and **K** by means of the bolts above them. When 2½-in. metal is required, the stroke, measured at the lower extremity of the jaws, should be ⅝ in., but when crushing to 1¼-in. gauge, or less, it should be reduced to ⅜ in. The sizes of jaw-crushers are indicated by the dimensions in inches of the opening or mouth through which they are fed. The standard size for road work is 16 x 9, which at 280 revolutions per minute is capable of crushing, elevating, and screening about 10 cubic yds., measured loose, of average 2½-in. gauge basalt per hour, when driven by an engine of 8 n.h.p., equivalent to about 24 indicated h.p. The power required is about in direct proportion to the gauge, that is to say, the power required to break 1¼-in. metal is about double that required for 2½-in. Larger sizes, including 20 x 10, 24 x 12, and 30 x 18, are made, but seldom used in road metal quarries, the reason being that, owing to the limited space round any crusher, a 16 x 9 is just about as large a machine as can be fed by two men.

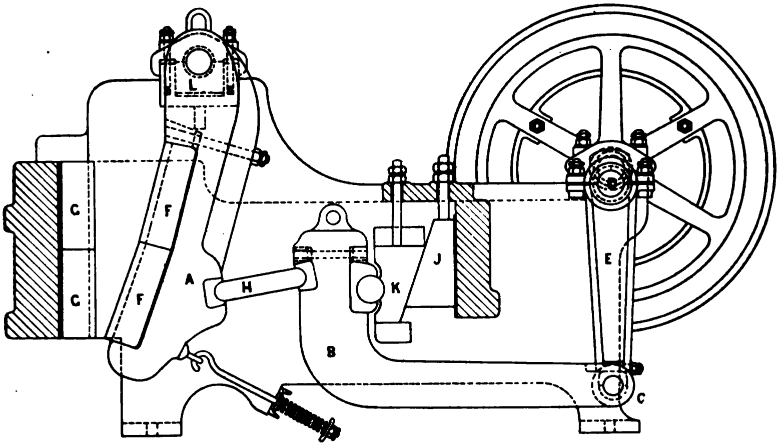


Fig. 53.

Section of Jaw Rock-Crusher.

143. **Rotary Crushers.**—A rotary rock-breaker of local manufacture is shown in Figs. 54 and 55. The vertical shaft **A**,

on which is mounted the cone head **B**, is supported on the chilled iron step block **O**, and revolved eccentrically with respect to the outer frame by means of the bevel pinion **J** and the bevel wheel **I**, actuated by the countershaft **L**, held in position by bearings **U**, and driven by the pulley **K**. The machine is fed at the top, and the spalls are broken between the cone head and the crushing rings **C**, the product being discharged by the shoot **S**. Dust is excluded from the lower bearings by the top dust ring **G** and the bottom dust ring **H**. No. 0 is the smallest size made, with three openings, as at **E**, 5 in. x 16 in. In No. 2 the openings are 7½ in. x 24 in.; the capacity is about 10 cubic yds. per hour of 2½-in. gauge basalt, and the power required to drive the crushers, elevator, and screen is about 15 indicated h.p.

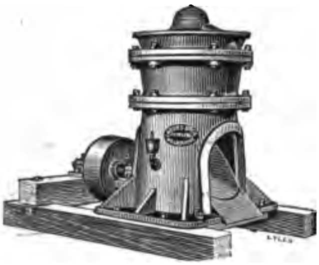


Fig. 54.

These crushers require rather less engine power than those of the reciprocating type, but the adjustment regulating the gauge cannot be made so readily, nor is the product so cuboidal. Although both classes are used for the production of road metal the advantage seems to lie with reciprocating breakers, which are recommended as preferable for the purpose. When the stone is to be used for concrete, or when ore is being broken down prior to milling, shape is of less importance, and either type is satisfactory.

144. **Screening.**—The various sizes of material are sorted out by means of revolving screens, with circular perforations of varying size, the smallest being at the upper or feed end. The sorted stones drop directly from these perforations into the several hoppers, as shown in Figs. 50 and 51, or are directed to their respective bins by means of inclined shoots. Hoppers and bins are essential to success in fixed plants, otherwise either the machinery can only be run when wagons are in position to load, or the stone has to be rehandled at extra cost. The usual practice in portable plants is to elevate

directly into the drays, though movable bins similar to the one illustrated in Fig. 56a have been introduced with great success for use with portable plants. The old style of screen is mounted on a central shaft, to which the perforated plates are secured by iron spiders. In the latest type of revolving screen the perforated plates are made up in cylinders of convenient lengths, and when butted together are secured to four external angle bars running lengthwise, and connected with the screen head, which revolves on friction rollers. Rotary

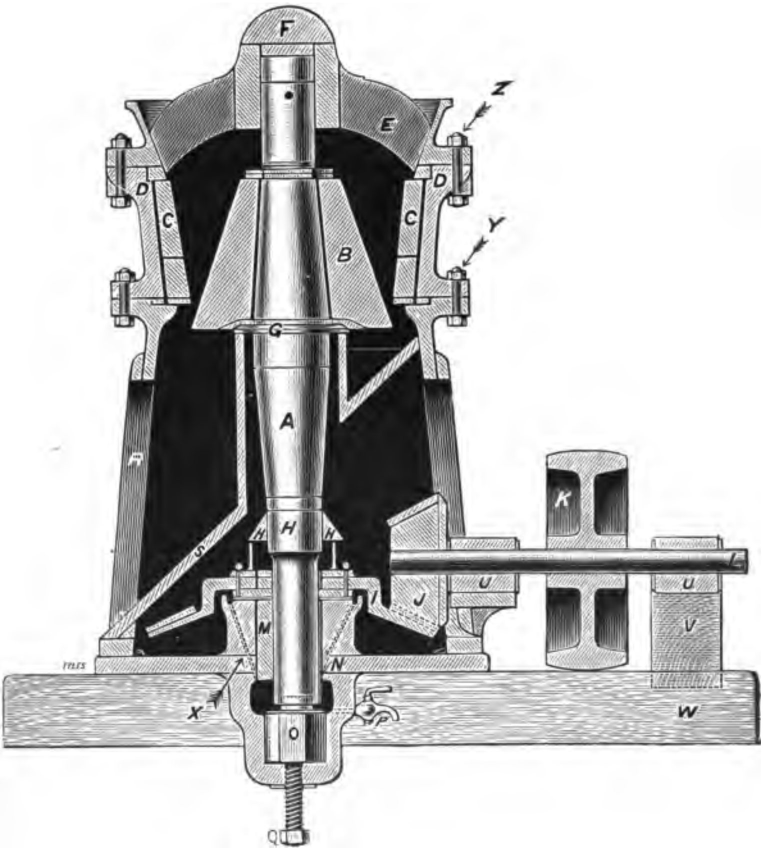


Fig. 55.

Rotary Ore and Rock-Breaker.

motion is imparted through bevel gearing at the tail or lower end of the screen. The facility with which sections of the screen can be changed to meet altered requirements and the elimination of the central shaft are important features. Screens are usually set at an inclination of about 1 in 8 to the horizontal when operating on road metal. Their diameters vary with requirements, but should never exceed 4 ft. An average size of screen for one 16-in. x 9-in. crusher intended to produce 2½-in. metal is about 12 ft. long by 2 ft. 6 in. diameter, divided in four sections, with perforations ⅛-in., ½-in., 1¼-in., and 2¾-in. diameters respectively.

145. **Portable Plants.**—Fig. 56 shows a recently constructed portable plant, with all the latest improvements, weighing 12½ tons in all, and fitted with a 16 x 9 crusher, capable of breaking and elevating about 80 cubic yds. of crushed metal per day of eight hours..

These machines can be moved at a moment's notice, as no dismantlement is required before shifting to a fresh site. The machinery is usually driven by a portable engine, but it is far better to provide a traction engine that can not only drive, but also haul the whole plant about the country. With portable plants it does not always pay to reject over-sized stones and return them for recrushing. Some machines provide for this, however. Plants of this description are just what is required by metal contractors or shire councils. It is to be hoped that it is only a matter of a short time before their use becomes general.

Fig. 56a. illustrates a type of semi-portable bin, introduced by the Acme Road Machinery Co., that is a decided acquisition to portable plants, enabling the metal to be screened, and the crusher to be run continuously during working hours independently of the carts or wagons. These bins are also made in sizes up to 50 tons capacity for mounting on wheels, and have proved very serviceable.

146. **Cost of Crushing Plants.**—The cost in Australia of a complete portable plant with 16 x 9 crusher, such as illustrated

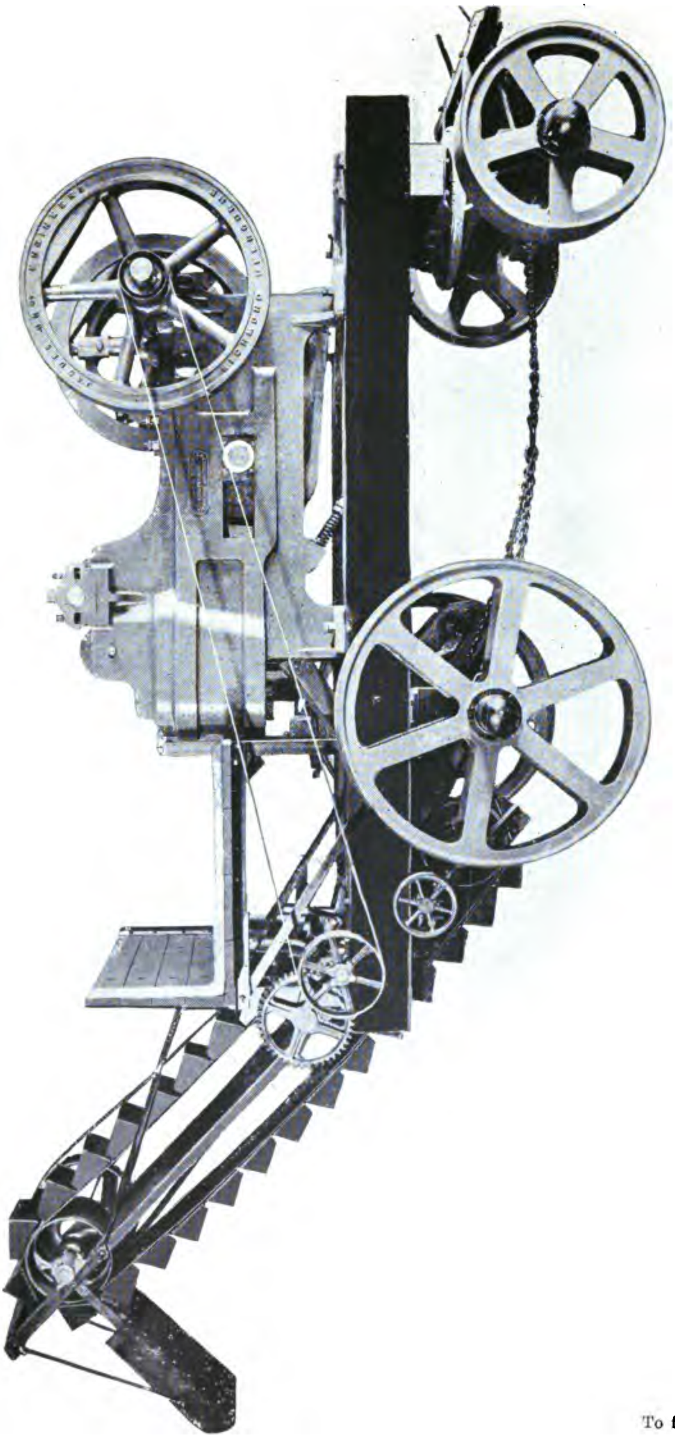


Fig. 56.—Portable Crushing Plant.

To face p. 148.

in Fig. 56, together with a traction engine, is about £1000. If with a portable instead of a traction engine £700 will about cover the cost. Fixed plants vary so much in size and arrangement that it is impossible to give figures of general application. Satisfactory outfits, with one 16-in. x 9-in. crusher and suitable engine, elevators, screens, and buildings, can generally be installed for £800 to £1000.

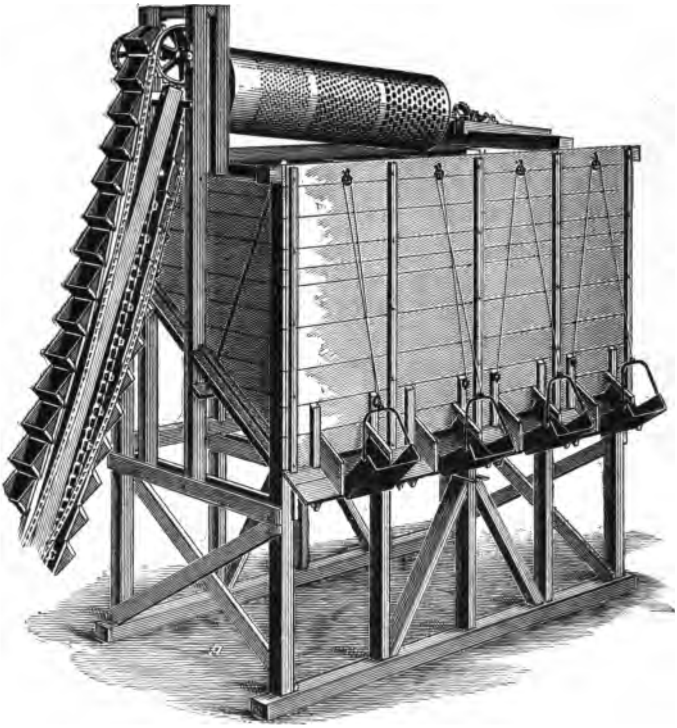


Fig. 56a.

Semi-portable Bin of 40 Tons capacity, with Elevator and Screen.

147. Cost of Crushing and Screening.—The following figures give the approximate cost of crushing average basalt to 2½-in. gauge with one 16-in. x 9-in. crusher, with elevator and screen.

The daily running charges, assuming the plant is worked 150 days per annum, are about as under:—

	s.	d.
Engine driver	10	0
Two men feeding	14	0
One boy	4	0
Fuel and water	14	0
Oil and waste	2	6
Depreciation and minor repairs	6	6
Interest on plant costing, say, £800	5	0
	£2 16	0

Allowing for minor delays the daily output may be taken at 60 cubic yds. of 2½-in. metal and screenings, the cost amounting to practically 11d. per cubic yd., measured loose. It will be noted that full credit is taken for screenings, toppings, and dust, as these are generally quite as valuable for other purposes as the larger stone is for macadamising. When estimating on the basis of solid stone crushed remember that 1 cubic yd. of solid rock produces about 1¾ cubic yds. of broken stone.

In larger plants, where two or more crushers are employed, the cost of crushing is for obvious reasons materially reduced, and, taking interest and all charges into consideration, may, under favourable circumstances, go as low as 8d. per cubic yd. for 2½-in. gauge. Diabase and other extremely hard rocks, which must be broken to finer gauge, cost about 50 per cent. more than the figures given herein. The prices mentioned above do not include the cost of transporting the stone from the quarry face to the crusher. The charge for this will run from 4d. to 7d. per cubic yd., depending on circumstances.

148. Total Cost of Road Metal.—The approximate average cost, delivered on the roadside, of broken basalt, 2½-in. gauge, obtained from a small quarry and carted one mile, and exclusive of contractor's profit, is summarised as under:—

	Pence per Cubic Yard of Screened Metal Measured Loose on Delivery.
Royalty, say	2.0
Quarrying, see Table II.	21.7
Transporting to crusher, say	7.0
Crushing and screening, see § 147...	11.0
Loading and carting one mile	12.0
	53.7

Say, 4s. 6d. per cubic yard.

In large quarries average figures for basalt, which need not be varied greatly for granite, would be about as under:—

	Pence per Cubic Yard of Screened Metal Measured Loose on Delivery.
Royalty	2.0
Quarrying, see Table XII.	14.7
Transporting to crusher, say	6.0
Crushing and screening, see § 147...	9.0
Loading and carting one mile	12.0
	43.7
Say, 3s. 8d. per cubic yard.	

If the metal has to be transported by rail the cost will, of course, be increased according to circumstances.

CHAPTER IX.

CONSTRUCTION OF METALLED ROADS.

149. Where hard rock is obtainable few forms of pavement are superior for country and suburban roads to a surface of broken stone, often termed macadam, after the famous road builder of the eighteenth and nineteenth centuries. When the cost of constructing a hard, smooth surface is warranted by the nature and volume of the traffic (see §§ 11 to 15, Chapter II.) broken stone has in such situations many advantages in the matters of cost and efficiency over pavements of any other kind. Under heavy city traffic macadam wears rapidly, and requires so much maintenance that a pavement of more durable material, such as woodblocking, is more suitable. Before proceeding to the permanent improvement of an existing road, its location and grades should be well considered. The principal difficulty is with the grades, many of which are too steep and long as now located to be reduced by cutting and filling. The importance of deciding whether there is any necessity for relocation before costly construction is undertaken cannot be overestimated; everybody knows how difficult it generally is to arrange for subsequent deviation, no matter how desirable that may be.

150. **Telford and Macadam.**—In the early part of last century there were introduced into England two systems of construction, one by Telford, the other by Macadam. The former followed the principles laid down by the French engineer, Tresaguet, who, half a century before, designed roads with a close foundation pavement of spalls set by hand, the interstices being filled as far as possible with stone chips, hammer packed. Macadam discovered that it was unnecessary to provide a foundation of large stones set on edge, and introduced the practice of spreading broken stone directly on a well-consolidated earth foundation. The wearing coat under either system was a layer of broken stone consolidated by the passage of horses and carriages.

151. **Modern Telford.**—Telford's practice was to place the pavement on a level base, and to make it thicker at the centre

than at the sides, so that its upper surface was parallel to the crown. Modern practice is to prepare the base, or sub-grade, with the same convexity that the finished surface is to have, and to provide an equal depth of road material throughout. The pavement course is generally made about 7 in. thick of stones not longer than 10 in., nor wider than 4 in., with the broadest face downwards, and breaking joint as far as possible. The interstices are filled with stone chips firmly wedged with a hand hammer, all irregularities and projections being broken off so as to leave a fairly smooth surface, which is rolled by a steam or other heavy roller. Over the road bed so formed a layer 1 in. to 2 in. thick of gravel or even clean sand is spread, the object being to prevent the fracture of the superimposed stones under heavy loading. On top of this broken stone is spread to a depth of about 5 in., and rolled and bound as described in the following pages.

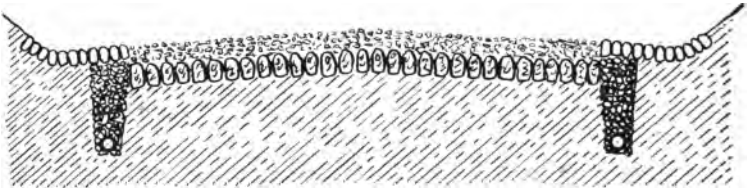


Fig. 57.

Section of Telford Road in Cutting through Wet Ground.

Fig. 57 shows a method of construction suitable for a road in cutting where the subsoil is wet, and where the natural foundation is unstable. As an alternative a layer of good binding gravel 6 in. thick can be substituted for the pavement with almost equally good results, and very often at a reduced cost.

152. **Rock Bottom Roads.**—The tendency of modern practice is to combine to some extent the methods of Macadam and Telford by laying a bottom course 6 in. or 7 in. thick of rough spalls, 4-in. to 6-in. gauge, on a well-consolidated earth bed. Hand packing is not required, but coarse metal is spread on the stones so as to level up the top and to wedge the spalls into position when rolled to a fairly smooth surface. Binding is not applied to this foundation course, although a layer of

gravel or coarse sand 1½ in. thick is an advantage. The wearing coat, at least 4 in. thick, is of 1½-in. to 2½-in. gauge metal, according to the quality of the stone and the nature of the traffic. Binding and rolling are carried out as described further on. Exception has been taken to this method on the ground that stones over about 2½-in. gauge gradually work to the surface. This is attributed to the repeated tiltings of the larger stones under the weight of wheels and the sinkage of smaller ones into the cavities formed under them. While such is true of roads constructed by the rules of Macadam, without binding and rolling, the assertion is misleading when applied to modern construction. Close observation shows that where binding is provided stones a couple of inches and more below the surface are so firmly bedded after rolling that there is no fear of their tilting or rising under ordinary traffic.

153. **Modern Macadam.**—The conditions under which metalled roads are constructed have completely changed since the days of Macadam; for this reason the rules laid down by that eminent engineer should no longer be followed in their entirety in this or any other country. Modern methods of construction, to a large extent rendered possible by the invention of crushers and steam rollers, differ from those of his time in several particulars, as detailed below.

1. Macadam specified hand-broken stone in all cases for the very good reason that rock-crushers had not then been invented. Most engineers of the present day realise the necessity for using modern machinery if work is to be carried out at a reasonable cost. While some follow ancient precedent in the belief that the hand-broken stone is vastly superior, others are compelled to adopt antiquated methods because of the parsimony or conservatism of their employers, who may not have learnt the economy of rock-crushers. On the subject of hand and machine broken metal see § 140.
2. It has been customary to use hand-broken metal just as it comes from breakers' heaps. As pointed out in § 140, such metal usually contains an excess of fines that should be screened out.

3. Macadam limited the size of the stones to cubes of about 1½ in. in their greatest dimension, and the weight to 6 ozs. With suitable binding and rolling, stones up to much larger gauge have been found satisfactory, see § 168.
4. He prohibited most emphatically the employment of binding of any sort, whereas experience shows that, for reasons stated in § 174, extraneous material other than stone is required to ensure early consolidation and permanency.
5. Consolidation by wheel traffic was insisted on by Macadam, probably because heavy rollers, although invented, were not in general use. The result was to cut ruts in the loose metal which often penetrated to the soil beneath, and to abrade the angular edges so much relied upon to ensure interlocking of the stones. The practice, so common half a century ago, of forcing traffic on to loose metal, is so cruel and unsatisfactory that binding and rolling are now regarded as essential. In Australia the greatest enemy to roads is the long dry summer, and the road engineer must take care to do his work so that the crust shall not break up during this critical season. English practice does not in all respects suit our conditions, and we must, therefore, take care how far we accept the conclusions of English authors. By adopting methods suited to local conditions, and making full use of modern machinery, a metalled road can be so built, that it will be harder and smoother within one week from the time of spreading than it would be in three months under the old system, while, given reasonable maintenance, loose stones and ruts should be things of the past.

154. **Choice of Methods.**—The advocates of Telford's methods hold that the open foundation course is essential for proper drainage. The fact is, however, that the principal function of the pavement is not to afford drainage but to give better distribution of superincumbent weights, especially

where the road traverses wet, springy ground. The surface layer of metal is intended to form not only a smooth wearing coat, but to provide a covering that will prevent water reaching the foundation from above. Ground water should be intercepted by side and subsoil drains, and no reliance should be placed on Telford paving as a means of drying the road foundation. When the bed is clayey or swampy, Telford, or rock bottom construction (see Fig. 57), is strongly favoured as being superior to broken stone alone, but a cushion layer of gravel, sand, or ashes sufficiently thick, say 3 in., to cut off the road material from the soil, which in time works its way up, is a very great advantage. Rock bottom is not as effective as hand-packed Telford, but is much cheaper, and, in ordinary cases, makes a fair substitute.

Where drainage is satisfactory, and when the road bed is firm but not unduly hard, any one of the three classes of construction mentioned gives almost equally good results, and the choice of methods should be governed by the relative costs. In localities where a crusher is not available, it is often cheaper to lay a Telford pavement, or rock bottom, than to hand-break the whole of the stone. Stones of sizes suitable for rock bottom can frequently be gathered near the works and be laid without much breaking down. Then, again, softer rock can be employed in the lower course than in the wearing coat with perfectly satisfactory results. On the other hand, modern tendency is to reduce the thickness of macadam roads and to economise stone. A carefully-prepared estimate will disclose the most economical construction. Should there be but a slight difference in cost, preference should be given to Telford or rock bottom, unless it happens that the foundation is hard rock, in which case the rigidity and unyielding nature of a pavement course conduces to the destruction of the road, more especially when the wearing coat is all but worn out. In such cases a layer of good clean gravel or sand about 1 in. to 2 in. thick interposed between the bottom and the wearing crust is necessary.

155. **Foundation.**—The consequences of unevenness of settlement are so fatal that the greatest care must be taken with the preparation of the earth foundation. The best results

will be obtained by waiting a year or more before spreading metal on imperfectly consolidated embankments. A well-beaten earth or gravel road makes a first-class foundation for metal, provided that it is properly crowned and graded, all dust or mud being removed before the metal is applied. If the ground is waterlogged or spongy, a system of under-drainage must be installed. All that is written in § 70 on the subject of subsoil drainage of earth roads applies with even greater force to metalled roads. There is no doubting the fact that in Australia we have been rather neglectful of this important detail of construction. A sub-drain on one side of a road is generally sufficient; in cases where there is doubt as to the side on which the spring rises, a drain should be placed on each side, but never under the metalling. Rolling of the subgrade is often neglected altogether, or carried out in a perfunctory manner, whereas a thorough consolidation of the road bed is of prime importance. Rolling is essential if only to pick out weak spots, which must be made up with similar material as the work proceeds. It often happens that steam rollers cannot venture on comparatively soft formations; horse rollers are very handy in such cases, but should be loaded as heavily as possible, it being remembered that the action of the feet of heavy horses pulling their hardest is in itself an excellent consolidator of earthen banks.

156. **Clay as a Foundation.**—Clay makes a very unsatisfactory road bed, for the following reasons:—

(a) Because it is highly retentive of moisture.

(b) Because when thoroughly wetted it becomes greasy, and, losing most of its supporting powers, allows the stones to work downwards.

(c) Because when dry its shrinkage is so great as to cause cracks.

In Chapter V., § 79, the question of improving clay roads by the intermixture of sand, and by burning, has been discussed and methods indicated whereby a satisfactory surface can be secured for an earth road. Where the road is to be metalled at once, it does not pay to go to the expense of burning, and the cost of mixing sand to any depth is unwarranted. The best and most practicable course is to pay particular attention to sub-drainage, and to withdraw the water as far as possible at an early stage in the work of construction. In clayey ground the formation should not be boxed out, as this tends to provide a receptacle in which water will lodge, to the detriment of the road. It is far better to spread and roll a layer of gravel, sand, or cinders at least 3 in. thick on the clay formation, which should be trimmed parallel to the finished surface, so that water will not lodge, before any metal is applied. Such a cushion layer assists drainage, and completely severs the broken stone wearing coat from the clay foundation.

157. **Sand as a Foundation.**—Sand being porous, and practically incompressible if confined, makes a good foundation for metalling, and expensive foundation pavements are quite unnecessary. The great difficulty lies in the waste of stone forced into the sandy subgrade during rolling. Strips of cheap cloth have been used to minimise the trouble, but not with the success that can be attained by spreading a layer of 2 or 3 in. of rather fine gravel on the sand before the metal is laid down. Clay should never be spread on sand as a bed for metalling. Further information on the subject of roads in sandy country will be found in § 81, Chapter V., and in § 258, Chapter XII.

158. **Rock as a Foundation.**—In cuttings where the bed is to be solid rock, a 2-in. cushion layer of gravel or sand should invariably be provided before any metal is spread. The reason for this is that broken stone placed directly on solid rock is very liable to be pounded to dust under the hammering of wheels acting, as it were, on an anvil.

159. **Crown.**—The amount of crown that should be given needs close consideration. Care must be taken not to barrel the road by making it unduly high in the centre; this is a common fault open to the serious objections mentioned in § 71, and is, moreover, a common cause of side slip so dangerous to motor traffic. As nothing, however, is more objectionable than a wet sloppy road, it is better to err on the side of too great rather than too little crown. The principal considerations affecting the transverse slope of metalled roads are:—

1. The centre must be higher than the sides by an amount that will cause water to drain readily, even when the metal is worn down 3 in., without scouring the shoulders, which, in country and suburbs, are generally of earth. On account of the likelihood of scour, wide roads are usually made somewhat flatter than narrow ones.
2. Hard surfaces, being less liable to develop ruts, do not need so much crown as softer ones. Remember that no amount of side slope, within practicable limits, will provide drainage for even shallow ruts or depressions.
3. On gradients the side slope should be greater than on nearly level stretches, the object being to prevent the flow of water along the formation rather than across it to the side ditches.
4. The amount of crown desirable depends to some extent on the state of repair in which the surface is likely to be kept. Metalled roads, in country districts where funds are scarce, will mostly likely receive less attention than suburban streets, and should be given slightly more crown to compensate for unevenness of surface. Table XIII. gives side slopes recommended for metalled roads under Australasian conditions when the gradients are flatter than 1 in 30; for steeper gradients increase the crown somewhat, but never exceed a side slope of 1 in 13 even on the steepest of roads.

TABLE XIII.

CROWNS FOR METALLED ROADS.

Class of Road.	Width between Outside Edges of Gutters.	Crown in Terms of Width of Metalling.	Side Slope.
City and Suburban	60 feet and over	1/50	1 in 25
Suburban	40 to 60 feet	1/40	1 in 20
Country	40 feet and under	1/36	1 in 18

160. Transverse Profile.—There is a diversity of opinion as to the best shape for the surface in cross section. The two forms of profile that meet with most favour are described and discussed below:—

(a) Curved Section.—An arc of a parabola is believed by many to give the best profile. The slope with this section is steeper at the sides than near the centre, with the result that the traffic seeks the middle of the road, wearing the crown hollow, so that water cannot run off as readily as it should. The most satisfactory form of curved profile has been found to be as illustrated in Fig. 58, in which ordinates at equidistant points are as indicated:—

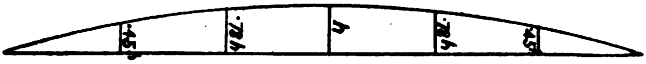


Fig. 58.

Curved Profiles for Metalled Roads.

(b) Straight Line Section.—In this two inclined planes are designed to meet at the centre with the crown slightly rounded off. The only objection to this form is that the flanks wear hollow in time, causing drainage troubles. When it is remembered that the greatest wear generally takes place at or near the centre, no matter what the profile may be, the straight line section, providing facilities for run-off from the crown, has its advantages. Experience of both leads us to the conclusion that, for metalled roads a curved profile, as per Fig. 58, less pronounced than recommended in most text-books, gives better results.

161. Cross Section of Country Roads.—Metalling is more often than not carried out on roads that have for years been in use as earth roads, with possibly the addition of a more or less useful coating of gravel. If the gradients and widths are satisfactory, extensive earthworks are not required, and a general reshaping of the formation is sufficient. When the improvements necessitate entirely new formation, care should be taken to so design the cross section as to facilitate the employment of modern machinery, including road machines and scoops. Deep watertables with steep batters like those shown in Fig. 21 should be studiously avoided, for the reasons given in § 71, and preference given to a design such as in Fig. 59, which is suitable where the road reservation is 66 ft. wide and the ground level transversely or nearly so. The footpath need not be specially prepared unless the pedestrian traffic warrants it.

For cross sections in sidelong ground, see Figs. 128 to 131. It is a mistake to design the cross section to which the road is to be built, irrespective of local conditions, for within the length of a few chains a road may be consecutively in cutting, on the surface, and in embankment. Whereas fairly wide shoulders between the metal and the watertables are desirable at all times for summer tracks and to enable vehicles to pass each other, their presence may be totally inadmissible in deep cuttings or on high embankments, owing to the extra amount of earthwork involved. In the preparation of contract drawings it is usual to supply typical cross sections of the formation in cutting, filling, and as surface work. The precise dimensions will depend on the arrangement of the grade lines and the equality of the contents of excavation and bank, but if the work is to be paid for at scheduled rates, no difficulty can arise in drawing up the contract. As to the width of metal, 12 ft. is sufficient in the country for all but main roads, on which 15 ft. is desirable.* Ten feet is not an economical width, being rather wide for one vehicle and too narrow for two to pass on. In sparsely settled districts, where rigid

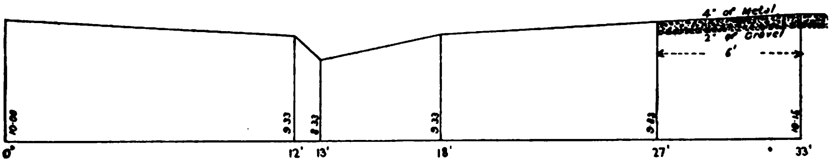


Fig. 59

Typical Half-cross Section of Metalled Country Road.

---

* Massachusetts Highway Commission's Report, 1901, p. 47.

economy is imperative, single track strips 8 ft. wide have proved satisfactory when passing places are provided by widening to 12 ft. at 10-chain intervals.

Observations on 180 metalled roads averaging 16 ft. wide showed that the width of the commonly travelled portion was only 11 ft. In Massachusetts the standard width of the †State highways is 15 ft., with shoulders of 3 ft., shaped to the same cross section as the broken stone, gravelled where the traffic is heavy, but in natural soil in ordinary cases. For Australasia somewhat wider shoulders are desirable where the ground is level enough to admit of their inclusion at a reasonable cost. In fact, in flat dry districts, where for eight or nine months in the year drivers prefer an earth track to a hard road, a cross section similar to Fig. 20, Chapter V., is recommended; a great deal of wear and tear of the central metalled formation is saved where there is room enough for earth trackways.

162. Varying the Levels of Streets and Roads.—Radical alterations of levels of streets in towns are not practicable when once the properties abutting on the roads have been improved. Owners naturally object to deep cuttings or high embankments in front of their houses or shops, and municipalities proposing to cut down or embank roads must beware of actions at law by dissatisfied ratepayers. The Local Government Act 1903 of the State of Victoria provides that councils may fix the levels of streets at the time of construction, subject to appeal by aggrieved persons to a Court of Petty Sessions. In the event of any subsequent alteration of levels, compensation must be paid to all persons interested in any property injuriously affected. Where cuttings or embankments are really necessary to eliminate steep gradients, it is better to compensate than to spoil the road; in business streets where shops are already built, extensive regrading is almost out of the question, even if the grades are not satisfactory. When grading country roads, the excavation should balance the filling, but in town streets balancing of earthwork is generally impracticable, and the soil is frequently used to fill low-lying ground.

---

† Massachusetts Highway Commission's Report, 1901, p. 17.

163. Width of Footpaths.—The sidewalks may be any width from 5 ft. to 20 ft., depending on that of the street, upon the nature and volume of the traffic, and upon the position assigned to ornamental trees. Generally speaking, trees are best placed close to, but on the road side of, the open channels. On very busy town or city streets an exception should be made, and the trees placed on the path close to the kerb. A good rule for streets under 100 ft. wide is to make each footway, the full width of which is not necessarily paved, between one-fifth to one-sixth of the total width. On 50-ft. streets each path should be about 10 ft. wide, on 66-ft. streets 12 ft., and on 99-ft. streets 18 ft. is a suitable width even in large cities, though 20 ft. is better when trees are planted on the path. On three-chain roads 24 ft. paths are permissible. Many of the paths constructed in the early days were too narrow, and, of recent years, considerable expense has been incurred in widening them to meet the requirements of pedestrian traffic. For example, quite a number of footways in 66-ft. streets, originally constructed 9 and 10 ft. wide, have had to be increased to 12 ft. Another point to be remembered is that unduly wide carriage-ways involve additional charges for upkeep that are not always warranted. For roads over 100 ft. wide, 20 ft. may, except in rare cases, be regarded as a maximum width for the main footpaths. Other portions may be occupied by strips reserved for plantations, shrubberies, tramways, &c., referred to below.

164. Cross Sections of Town and Suburban Streets.—Having fixed the widths of the paths, the next step is to decide on the cross sectional slopes. Care must be taken in this country, subject to heavy storms, to give the footways sufficient transverse fall, or they will not shed the water quickly enough. Paths with a gravel surface require a fall of about ½ in. per foot, tar pavement ½ in. per foot, cement or other comparatively smooth surfaces should be given ⅜ in. per foot, while ¼ in. per foot is a minimum that may occasionally be adopted for asphaltum pavements. It will be noted that the transverse slopes here set down are somewhat steeper than generally adopted in England, where, when the paths are covered with ice and snow, there is great danger of slipping if the slopes are at all steep. It follows from this that pavements likely to become slippery should not be constructed on considerable longitudinal slopes.

The sole course of the gutter will be at least 6 in. below kerb level, or that of the toe of the path in the absence of a kerb, but rarely more than 12 in. When the channel is deeper it is not only awkward to step over, but sometimes dangerous. In fixing the level of the channels or gutters, care must be taken to provide for the discharge of surface or roof water from adjacent allotments, as well as from the road itself. Stoneware pipes are generally laid under the footpath to convey water from houses, and the channels must then be kept down so as to allow sufficient cover to the pipes, which should not be less than 4 in. internal diameter. The channels should, when possible, be laid with a fall sufficient to generate in them an almost self-cleansing velocity. Although desirable, it is not essential, nor is it always possible, to give the channels the same longitudinal fall as the crown of the road. In fact, the road surface may be perfectly level, while the gutters are arranged with slopes alternately in opposite directions, flowing to gullies or culverts discharging below ground level. The levels are often dependent upon the heights of doorsteps, cellar gratings, and other fixtures that must be retained at or about path level.

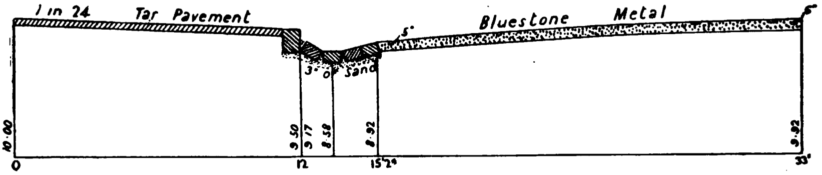


Fig. 60.

Half-cross Section of a Town Street 66 ft. wide, Metalled Full Width between Channels.

In every case a general scheme of street grades should be decided upon before the construction of isolated lengths is undertaken, otherwise expensive alterations will almost certainly be required at some later date. The gutter will have a rise of at least 1 in 5 from the sole course towards the centre of the road, and its width will depend upon the amount of water to be discharged. The crown of the road between the edges of the channels can be designed from the data given in Table XIII., and the profile from the data given in Fig. 58.

Fig. 60 shows a typical half-cross section of a town street metalled full width between channels. Residential suburban streets may be of similar cross section, but the metalling is more often confined to a strip about 16 ft. wide on which loaded vehicles can pass with ease. If the flanks are sandy or likely to produce much dust they can be gravelled with advantage; the washings of a broken stone road bind sandy flanks in time, but they are certain to break up if subjected to much traffic. Clayey flanks should be gravelled or sanded.

Fig. 61 shows a design for a three-chain road approaching a city in which there are two main carriage-ways with plantations between them and a reserve down the centre of the road for a double line of electric tramway.

Fig. 62 shows an alternative design for a wide road on which the main carriage-way, with tram lines, occupies the centre of the road. The side roads are intended for lighter traffic, including motor cars.

The design illustrated in Fig. 62 provides for a large volume of traffic, but it is liable to be dusty, more especially to those patronising the tramcars. In Fig. 61 the tram lines are away from the carriage-ways, and the plantations on either side, acting as fairly effective wind-breaks, assist in preventing the formation of clouds of dust. Fig. 63 illustrates an alternative arrangement whereby motor, as well as tram traffic, is provided for.

165. Cross Section on Sidelong Ground.—In practice there is frequently a difference of level between the ground on opposite sides of a street which, for some reason, cannot be eliminated.

Comparatively small differences may be overcome by arranging the kerbs at a varying height above the street channels, as shown in Fig. 64.

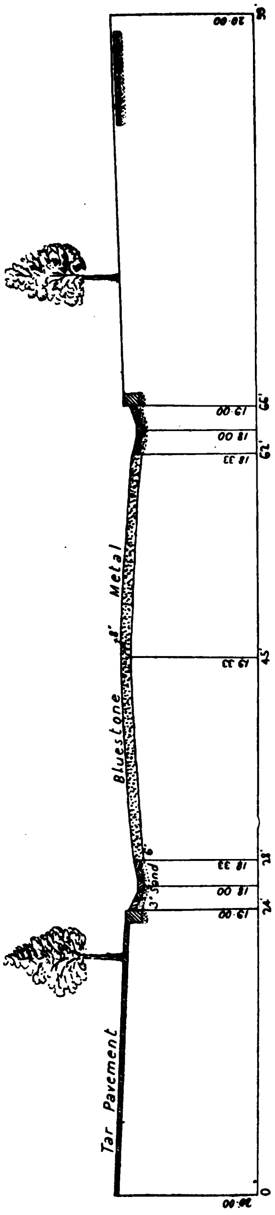


Fig. 61.

Typical Half-cross Section of a Three-chain Road approaching a City. Compare with Figs. 62 and 63.

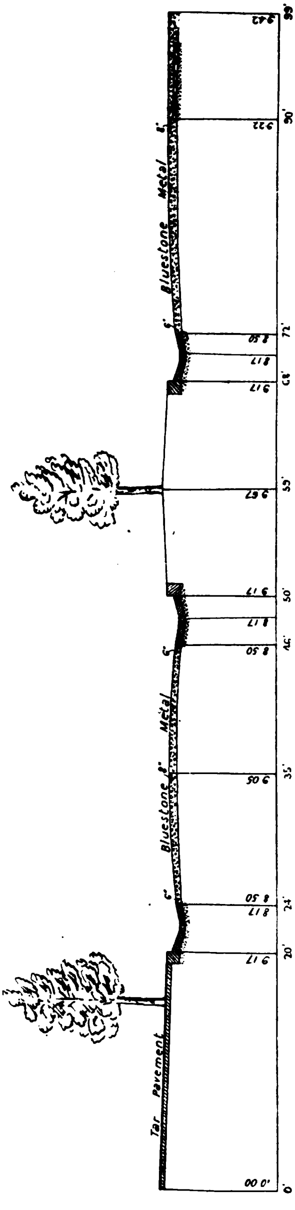


Fig. 62.

Typical Half-cross Section of a Three-chain Road approaching a City. Compare with Figs. 61 and 63.

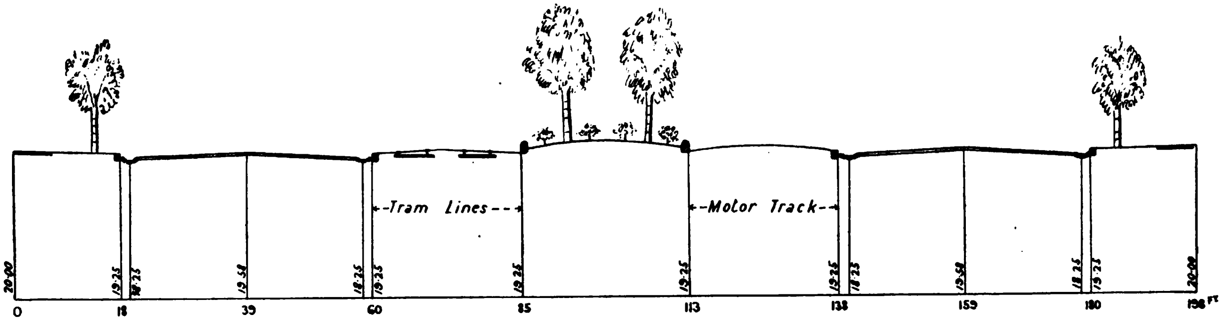


Fig. 63.
Cross Section of a Wide Road with Provision for Tram and Motor Traffic.

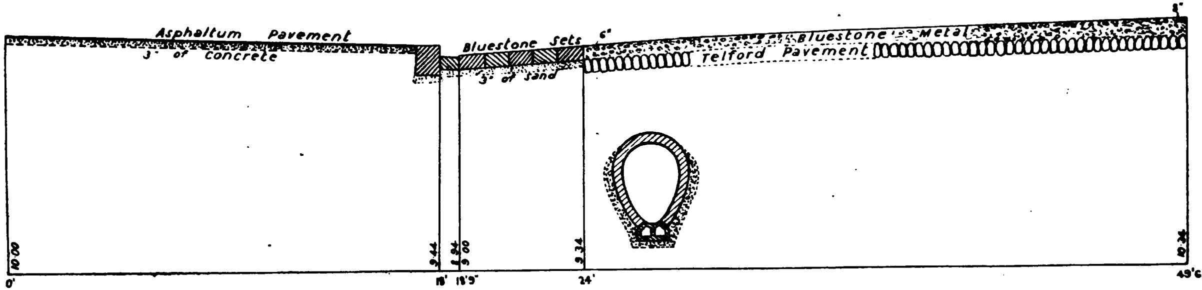


Fig. 69.
Half-cross Section of a City Street. (See § 166.)

The double kerb shown in Fig. 65 should be avoided whenever possible. It is not only expensive, but rather dangerous in the event of a person slipping. The arrangement in Fig. 66 is to be preferred when valid objections cannot be raised by abutting owners on account of the step at the building line.

Fig. 67 illustrates another expedient by which the crown is unsymmetrically placed, giving the road a lopsided appearance. Design shown in Fig. 68 with a straight slope is preferable, the only objection, which is not very serious, being that the whole of the surface drainage from the roadway flows to one gutter.

In extreme cases, as in Dunedin, New Zealand, the path on one side of a street may be at the level of the third floor window of the houses on the other side. Here, of course, long flights of stairs are constructed, and expensive retaining walls may be necessary.

166. Cross Sections of Metalled City Streets.—As already mentioned, macadamised stone roads are not really suited for very heavy traffic. However, owing principally to lack of funds, roads of this description are, and will continue to be, built in many cities for some time to come. A typical design for a city street is illustrated in Fig. 69, page 167, which, in the light of what has been written, is self-explanatory.

167. Thickness of Metal.—It was at one time the custom to construct roads with great thicknesses of stone, but such practice is condemned nowadays as not only useless but wasteful of good material.

Figs. 70 to 73 illustrate methods in vogue at different periods, and show the relative thickness of ancient and modern roads.

The load on wheel tires is transmitted through the metal to the foundation, much in the same way as a weight resting on the frustrum of a cone is distributed over the larger area of its base. If the earth foundation is capable of sustaining the weight concentrated in a wheel without indenting its sur-

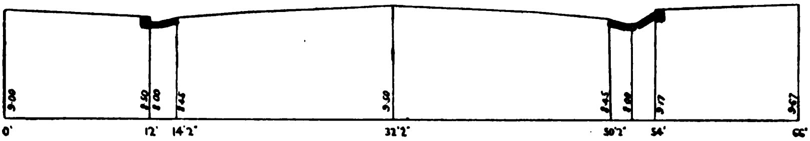


Fig. 64.

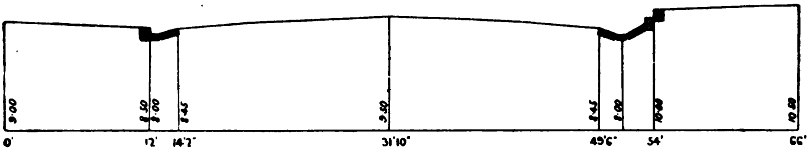


Fig. 65.

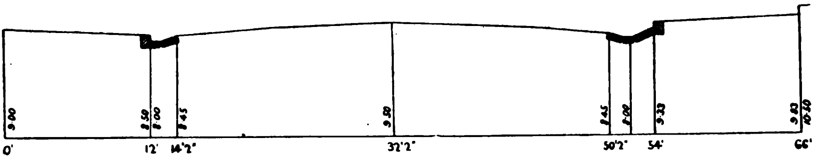


Fig. 66.

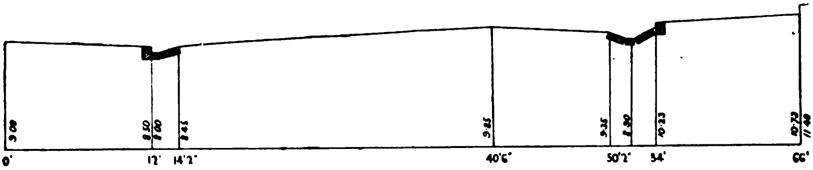


Fig. 67.

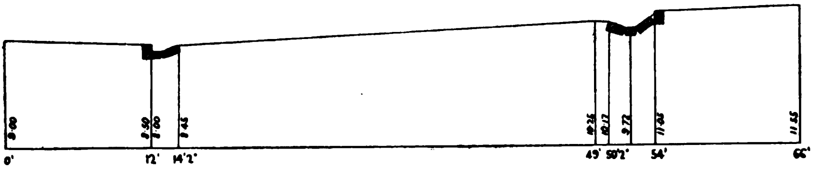


Fig. 68.

Cross Sections of Roads on Sidelong Ground.

face, then a coating of broken stone just thick enough to hold together under traffic is clearly all that is required. If, however, the foundation is weak, it is imperative to increase

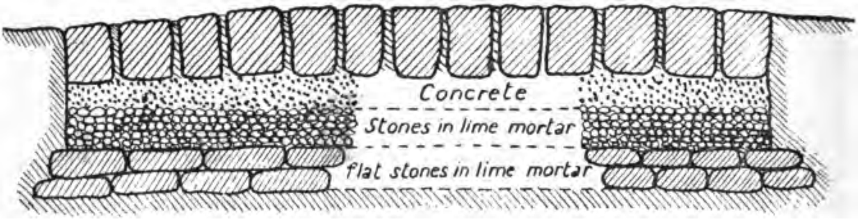


Fig. 70.

Roman Road.

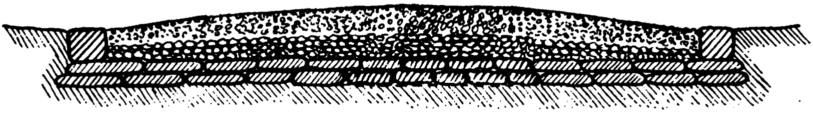


Fig. 71.

French Road Early Eighteenth Century.

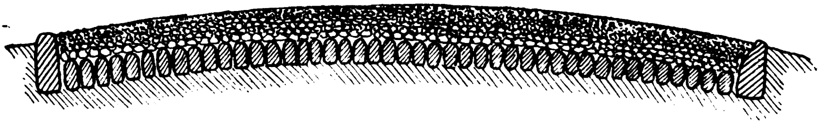


Fig. 72.

Trèsaguet Road Late Eighteenth Century.

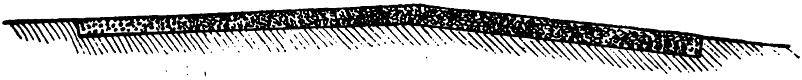


Fig. 73.

Modern Macadam.

the thickness until the weight is distributed over a sufficiently large area; that is to say, the pressure per square inch on the base of the metal crust must be reduced within safe limits.

The Massachusetts Highway Commission* suggests a rule from which the following formula is derived:—

$$d = \sqrt{\frac{l}{4P}}$$

Where **d** = depth of metal in inches
l = max. load in lbs. on each wheel
p = safe load on foundation in lbs. per sq. inch, varying, according to judgment, between 20 for sand, gravel and compact porous soils, to 4 for soft, non-porous soils well drained.

This formula is based on the assumption that the downward pressure takes a line at an angle of about 42 deg. with the horizontal, and is distributed over an area equal to the square of twice the depth of the broken stone. To the thickness required to support the pressure due to traffic, add an allowance of, say, 3 in., for wear before resurfacing. The tendency of modern practice has been to reduce the thickness of macadam; it is now realised that to lay down a coat of 12 in. thick, where one of 6 in. gives equally good results, is merely a waste of money and material.

Macadam roads 6 in. thick when compacted by rolling have been found sufficient under almost all conditions. On firm dry soil 5 in. of metal has made roads satisfactory in every way, the only fault being that very little margin is provided for wear before resurfacing becomes necessary; at the same time it may be said that, as a general rule, roads are not at their best till after resheeting. When estimating the amount of metal required, remember that about 1 1-3 cubic yards of loose metal compresses under the roller to 1 cubic yard of compacted macadam, exclusive of binding. Table IX., § 100, will facilitate computation of quantities for varying widths and thicknesses.

168. Sizes of Stones.—Macadam laid down the principle, unquestioned to this day, that as regards each layer there should be uniformity in size of the broken stone. For the lower layer 2½-in. to 3-in. gauge is most suitable, but for the wearing coat the size depends largely on the quality of the stone. The harder the rock the smaller it should be broken if a rough and uneven surface is to be avoided. On the other hand, soft stone must not be too small, or the road will be weak, and will wear out quickly. For moderately heavy traffic 2½-in. gauge is the maximum allowable when average basalt is used and a steam roller is available, while 3 in. may be regarded as the limit for any of the softer rocks, such as limestone; 2 in. should not be exceeded in the tougher basalts, while diabase of the quality described in § 125 should be limited to 1½ in. With the last-mentioned stone 2½-in. metal gives a surface destructively rough and very uncomfortable to travel on. For a definition of the gauge of broken stone, consult the typical specification § 179. There can be no doubting the fact that without close inspection it is difficult to secure metal of the specified gauge, more especially in the smaller sizes. This is often due to carelessness in arranging the size of the meshes of the screens, to an insufficient number of screens, or to passing the stone through them so rapidly that much of the smaller stuff finds its way to the wrong bin. For the design and working of crushing plants, see Chapter VIII.

---

* Report for 1901, page 15.

169. **Necessity for Screening.**—Some writers recommend that the output of a crusher should be utilised on the road, without screening of any sort, on the ground that the small stuff should be retained as binding. Most screenings, and nearly all stone dust, form fairly good binding, provided that they are applied in the right way, and at the right time. Neglect to secure thorough screening is, in the opinion of the authors, a great mistake. Stone pitchers wear but little under heavy traffic, say, for example, 1 in. in five years. An equal thickness of screenings and dust of the same stone would, if subjected to the same traffic, disappear in two or three months. Reasoning thus, we conclude that in a road composed of a mixture of stones, screenings, and dust there is a marked variation in the wearing capabilities of the materials. Close observation confirms the anticipated results; the weaker material crushes to powder, and, being washed or blown away, the larger stones project, the surface becomes rough and bumpy,

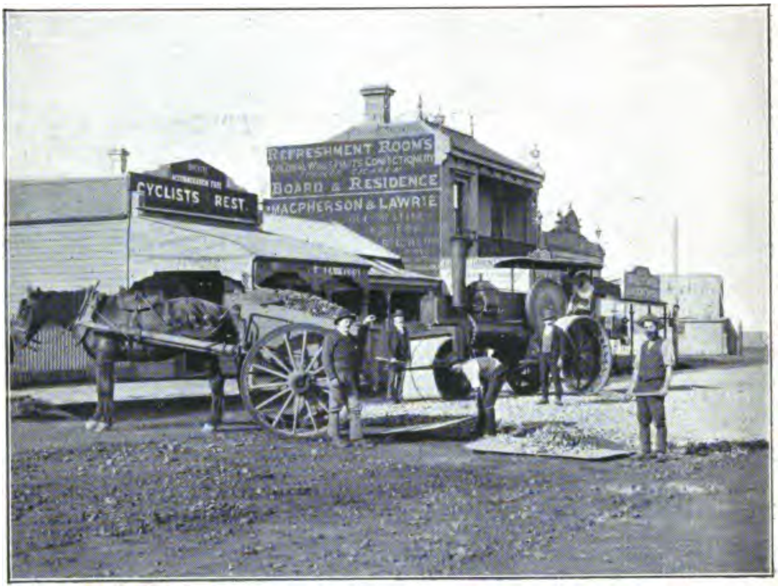


Fig. 74.
Spreading from Steel Plates.

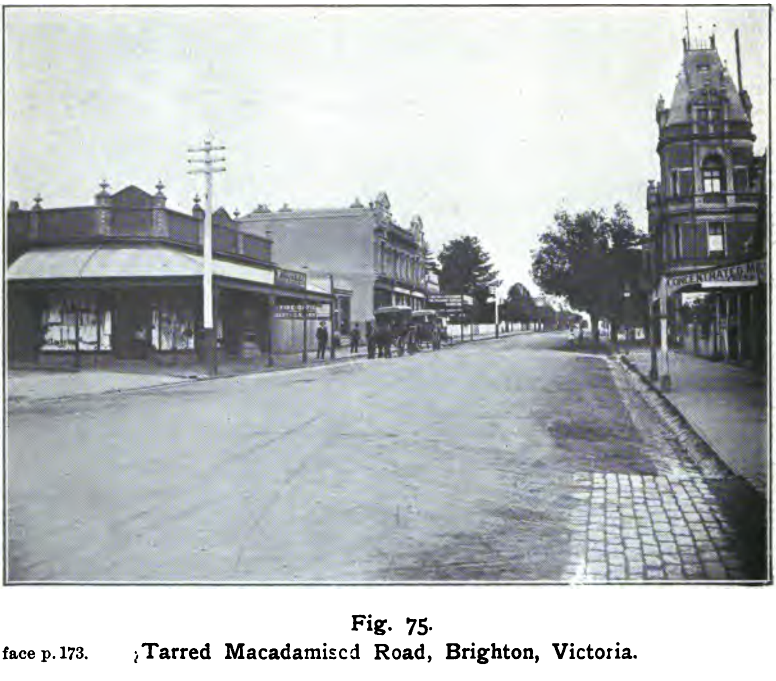


Fig. 75.
To face p. 173. Tarred Macadamised Road, Brighton, Victoria.

and finally breaks up. Another advantage of screening is that stones of a fairly uniform size present larger faces for contact than does a mixture of sizes. If small stones are admitted, they prevent the faces of the larger ones coming into contact, and a weak road results. Anyone who has noticed how the larger stones roll down the slopes of a bin and collect at the lower end will realise the necessity for separating the sizes by screens, if only to ensure an even distribution.

170. **Measurement of Metal.**—The quantity of metal supplied is best ascertained in the trucks or wagons, but the specifications must state whether measurements will be made at the loading or delivery station, as broken stone shakes down considerably (sometimes 10 per cent.) in transport. If the measurement is to be made on the road, and it is necessary to do so sometimes, the specifications should leave no doubt as to whether the depth is to be ascertained before or after rolling. The thickness after rolling can be ascertained approximately by measuring to canvas strips about 12 in. square laid down before the metal is spread. For further information on the subject, see § 100.

171. **Spreading.**—A really smooth, homogeneous road cannot be expected if the metal is tipped in heaps directly on to the formation, and spread all round from them. The stones in falling are sized, so that even with carefully-screened metal there are variations in the gauges and in the percentages of voids, though at first the surface appears even. The consolidation under rolling and traffic discloses these variations, and the inevitable result is a cuppy and uneven road. We have found that, having secured an even bed in new roads by careful formation and rolling, and in old roads to be recoated by the use of a modern scarifier, the best plan is to tip all the metal on a couple of 6 ft. x 4 ft. x ¼-in. steel plates laid side by side, and to scatter it from them on the formation so as to secure a homogeneous crust with about the same percentage of voids throughout, and that will consolidate to a smooth and even surface. The plates are easy to shovel off, and can be handled without difficulty by two men. In Launceston, Tasmania, board platforms are used in two sections, while in Maryland, U.S.A., timber platforms about 8 ft. square used to

be favoured. Having tried both wood and steel, however, the authors regard the latter as the better for the purpose. It may be taken that no amount of rolling or traffic will move the metal any appreciable distance from its position when first spread and rolled. Practically it only sinks, and if one square foot of an even and solid formation supports, say, 27 lbs. of stone, while all round the weight is 36 lbs. to the square foot, the certain result will be a cup or hollow about an inch deep.

172. **Rolling.**—In the construction of new roads the roller is required in the first instance to consolidate the subgrade; it pays to do this thoroughly, as it is much cheaper to make up inequalities appearing in the foundation than in the finished surface. If the depth of coating exceeds 6 in., the metal must be spread and rolled in layers. If a great thickness is rolled at one time the stones slide over one another instead of compacting, the effect being to break off the sharper angles so desirable for the interlocking of the metal coating. In all cases the stones must be fairly well compacted before binding in any form is added. Modern practice condemns the mixing of stones and binding,. and lays down the principle that the latter should be added merely as a filler when interstices are reduced by persistent rolling. Rolling should commence at the sides and gradually extend inwards. If the centre is rolled first there is a tendency to flatten out the metal and to destroy the cross section. Any inequalities that may appear must be made good at once by adding more metal of rather smaller gauge to the low places. Screenings should not be added for this purpose, as they produce a weak surface that will soon need repair. Steam roller drivers should be cautioned against discharging ashes on a road under construction; the authors have seen surfaces break up badly at spots where engine ashes have been thoughtlessly thrown down. After the binding has been applied, as described in the next paragraph, rolling should be continued until the added material has been well worked in, and a really hard surface produced. Consolidation by roller should not cease until a stone placed on the newly-made road crushes under the passage of the roller without indenting the surface to any great extent. Steam rollers are so much superior to horse rollers that they should

be in the possession of every municipality within whose territory stone roads are built to any considerable extent. In Australasia steam rollers are, unfortunately, rarely seen outside cities or large towns. The first cost deters municipalities from purchasing this most useful of machines, the interest on the price of which would not usually amount to more than about £35 per annum. The fact that large quantities of metal can be saved each year, and the facilities offered for scarifying and reshaping roads are completely overlooked in most cases. In view of the smoother and more lasting surface secured, and the fact that the working expenses of horse rolling are high (see § 186), we consider that any municipality that spreads more than 1500 cubic yds. per annum would be well advised in purchasing a steam or motor roller. While it is true that horse rollers are useful for light work in certain situations, and for consolidating earth formations, road foundations and paths, they simply won't compare with steam rollers for general road building purposes. On this subject a great deal of nonsense has been written by persons unacquainted with the first principles of road making. It may be argued that when roads are constructed by contract a municipally-owned roller is not required. The answer is that rolling, now so often a matter in dispute between engineer and contractor, can be, and has been, best carried out by the municipality with its own steam roller. Attention is directed to traction engines convertible to steam rollers, described in Chapter VII.

173. **Weight of Roller.**—The most suitable weight for rollers has been the subject of a good deal of controversy. The general opinion, however, is that where the materials are soft, a lighter roller will suffice than where tougher stone is used. Unduly heavy rollers crush soft stones to powder, and may do much harm. Light rollers are sometimes condemned because their weight per inch of width is less than the pressure on many vehicle tires. In this respect it must not be forgotten, however, that the function of a roller is not only to compress, but to assemble the stones. Steam rollers vary in weight between 8 and 30 tons. In France rollers weighing 20 to 30 tons are in common use. For city work a roller weighing about 15 tons is recommended, but in our suburban and country districts, where one only is kept, 10 tons is about

the best weight for general use, especially where the soil is naturally soft. In localities where there is work for two, the second should be heavier, say 15 tons. The lighter rollers can get about with less chance of bogging, and still do satisfactory work. In sandy ground there is always the danger of squeezing out the bed if too heavy a machine is employed. When purchasing a horse roller it is important to select a size that is suited to the work. If used in conjunction with a steam roller it will be employed on road foundations, on paths, and in places where the heavier machine cannot venture, and should consequently be light, say 2½ tons when unloaded. Where the whole of the rolling is to be done by horses, the heavier sizes should be selected, unless the roads are hilly, in which case a 3-ton roller may be all that six horses can drag. In fairly level country it is usual to allow one horse for every 1½ tons weight of roller. For weight, sizes, &c., of steam and horse rollers see Chapter VII.

174. **Necessity for Binding.**—The use of binding material, generally called with us "blinding," has probably created more controversy and excited more suspicion in the public mind than any other operation connected with road construction; to the present day many enthusiastic road critics view the proceeding with open hostility. Broken stone before rolling contains about 40 to 50 per cent. of voids, and no amount of rolling, even with the heaviest steam roller, will reduce the percentage of interstices by more than one-half. It must be obvious to all that a coating of metal containing 20 per cent. of voids cannot constitute a really solid mass. As a matter of fact the voids must be reduced to about 5 per cent. before the crust will set hard enough to withstand the compression and abrasion to which all roads are subjected. The addition of extraneous material other than stone is, therefore, imperative unless one is content to follow Macadam's practice, and wait some months for the abrasion of the stones themselves to produce filling for the voids. The old system, already alluded to, of forcing traffic on to loose metal, with the intention of consolidating it, is a barbarity that should not be tolerated in any civilised community. As a matter of fact, in New Jersey, U.S.A., as well as in other places, it is a criminal offence to allow broken stone to remain on a road without binding. More

humane methods by which roads are compacted within the space of a few days call most emphatically for the addition of binding; its omission cannot and should not be conceded, except in those rare cases in which the metal, limestone for example, is so soft as to crush and powder under the roller. Abandoning as impracticable the exclusive use of stone binding, the selection of suitable materials, as well as the quantity and method of application, will be briefly discussed.

175. **Bonding of the Road.**—The bonding action whereby broken stone roads are held together is as yet imperfectly understood. The medium of consolidation may be classified under one of the following heads:—

(a) Moisture.
(b) Rocks or rockdust with mechanical bonding properties.
(c) Rocks or rock dust with chemical cementing properties.
(d) Natural hydro-carbon mixtures, including tar and bitumen.

The three first mentioned will be considered in this chapter, the last in Chapter XI., when dealing with tar macadam.

Water.—An ordinary macadamised road will not bind until it has been either artificially watered or sprinkled by rain showers. The first proves that, whatever the nature of the cementing properties of binding may be, water plays an important part as a medium of consolidation. The bonding seems to be largely due to the capillarity existing between the particles, as exemplified by the setting of sand when wet. Solidification of wet sand is not due to any chemical change effected by water, because when dry the grains immediately become loose. That water is essential to cohesion of sand-bound roads is rendered evident by the ravelling of the metal in summer, and the marked and almost instantaneous effect of sprinkling in checking disintegration.

Mechanical Bond.—The angular rock fragments in binding material are supposed to interlock under pressure to some extent, and thus hold a road together. There is, however, but little evidence in support of the mechanical bond theory, and it does not seem to have any very great influence in the preservation of a road.

Chemical Bond.—In the selection of binding much store has been set, in certain quarters, by cementing properties of the material; to this end numerous experiments have been conducted to ascertain the relative values of rock dust in this particular, see § 123. Chemical action does not, however, appear to be essential to the bond. For instance, a newly-constructed road will, if properly treated and kept moist, become quite solid before crystallisation could possibly develop. The most noticeable effect of chemical action is the cementation due to iron oxide, or to carbonate of lime. While there is no doubt that high cementing properties are desirable, the authors believe that the presence of water exerts, in most cases, the preponderating influence in holding ordinary macadam roads together.

176. Selection of Binding Material.—In the selection of suitable material there is wide divergence of practice. Some engineers prefer metal screenings, others favour sand, clay, or loam, while others, again, very often against their better judgment let us hope, employ gutter sweepings or vegetable detritus. It may be laid down as a guiding principle that binding to be serviceable must be tough, unshrinkable, and inelastic. If we accept the conclusion that the binding is to a large extent held together by the surface tension of the capillary voids, the necessity for a material fine in texture is undeniable. Metal screenings without the dust left in are almost useless, especially those of basalt or trap rocks, as they possess but little cementing value. Coarse sand is not so good as fine, and, having little if any cementing power, is not satisfactory, especially in dry weather, As a fact, roads bound with clean sand almost invariably break up during an Australian summer unless continually watered. Sand alone as a binder is quite unsuited to this climate. Unscreened gravels, especially those containing iron oxide, are very valuable, and make probably the best binding if they contain a small percentage of clay. Screenings of limestone and other hygroscopic rocks condense moisture upon the surfaces, and, being highly cementitious, make excellent binders. Besides the iron oxide or lime constituent, that nearly everyone considers useful, the authors maintain that in a climate subject to considerable spells of drought a certain—not very large—percentage of clay is, on the whole, to be desired in a binding material, checking ravelling and reducing dust. They have closely observed the effects of motor traffic on roads (see § 270) bound with sand or screenings, as well as on those treated with ferruginous clayey sandstone, and have found that in dry weather the tires have very much less effect on the latter than on the former. Almost pure clay is sticky and greasy when wet, and certain to shrink and loosen the road in dry weather. For this reason it may be regarded as most undesirable unless mixed with sand or gravel. Road or gutter sweepings and vegetable matter of any sort should never be used, although the introduction of such stuff is too frequently seen. Modern engineers realise that any attempt to bind macadam with roadside turf is futile, and a practice that under any circumstances cannot be excused.

177. **Quantity of Binder.**—The quantity of binding should but slightly exceed the voids, which after rolling amount, as stated above, to about 20 per cent. of the volume of stone. In Australasian practice about ¼ cubic yd. of binding must be provided for each cubic yard of metal measured loose, principally because the binding itself is compressed under the roller. The quantities of materials, measured loose, required to make 1 cubic yd. of macadamised road average about as under:—

1.33	cubic yards of	loose stone.
.25	„	binding.
1.58	„	loose material.

Excess of binding, in addition to weakening a road, makes it muddy after rain, or even after watering, and correspondingly dusty in dry weather. Even when the binding material is not applied until after the metal has been rolled, an excessive quantity prevents direct contact between the faces of the stones. This is detrimental to stability, as, when thoroughly wet, the binding acts rather as a lubricant. Then, again, moisture will rise more quickly by capillary attraction through the continuous bands of clay from the bottom of the road and by loss from evaporation, the invariable effect of withdrawal of moisture being to bring about ravelling.

178. Application of Binder.—The binder should not be tipped on the metal, but should be spread in a thin layer, about ½ in. at a time, directly from carts or from heaps deposited on the roadside. On no account must binding be applied to the metal prior to preliminary rolling; if this precaution be ignored the result will never be satisfactory. As spreading proceeds, the binding should be worked into the voids by rolling. The binder is best applied in showery weather, when artificial watering is not required. If metalling is to proceed in dry weather the road must be sprinkled by water carts. When rapid completion of the work is desired it will be necessary to sweep the binding in with stiff brooms. When the metal is laid down in layers, each of them must be well rolled, but it is sufficient to apply binding to the surface of the top coat. Rolling is continued until the road is thoroughly hard and sufficiently consolidated to withstand the test mentioned in § 172. Should cool and moist weather follow its application, one coat of binding has generally been found enough, but should dry weather ensue, the stuff falls deeper into the interstices, and it becomes necessary to spread a second light coat, and to water after rolling. Very wet weather following this, it has been found a good plan to roll well during the rain and when the road is thoroughly saturated. The result of all these operations is a smooth, tightly-compacted crust, that becomes more or less cemented together, and wears evenly and well.

179. Example of Specification for a Metalled Road in a Country District:—

SHIRE OF.................... CONTRACT NO.........

SPECIFICATION referred to in the foregoing* Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement, and to be observed in the construction of roads as shown by plans attached hereto.

General Description.—The works of this contract consist of the clearing, forming, cross-drainage, metalling and channelling of about ....miles ....chains macadamised road situated as shown by locality plan. They will include all foundations, cuttings and embankments shown by drawings supplied, or to be supplied to the contractor, and the construction of all culverts and sub-drainage works that may be ordered.

---

* For specimens of these see Chapter XVII.

Nature of Contract.—It is to be clearly understood that this is a Schedule of Rates Contract, that the length of road to be made, the quantity of metal to be spread, the number of culverts to be built, and any of the items in the schedule may be varied as decided by the engineer, and that payment will be made at scheduled rates only for the work actually ordered and executed. Any work ordered but not scheduled must be carried out and paid for under Clause........ of the "General Conditions of Contract."

Clearing.—[In country where there are neither trees nor stones, no clearing clause is necessary. Where road has never been cleared insert specification for clearing, contained in Chapter V., § 82. Where road has been previously cleared insert the following:—] "The roads to be formed have been cleared, but all saplings, roots or stumps that may, in the opinion of the engineer, require removal must be grubbed out and burnt off or removed by the contractor, the cost being included in the scheduled prices for formation."

Formation.—The formation is to be in accordance with the drawings attached, or to be supplied, and great care must be taken to adhere closely to longitudinal profiles and cross sections. All holes from which trees, stumps, rocks, roots, etc., have been removed must be completely filled with approved material well rammed or otherwise consolidated.

Embankments are to be carried out in such a manner as to ensure their being, when thoroughly consolidated, of the specified dimensions as shown on drawings, and in carrying an embankment over any bridge or culvert, provision must be made for bringing it up equally on both sides of such bridge or culvert, and so consolidating it that the weight of the earth may be properly distributed. In sidelong ground, or in adding to existing embankments, slopes must be benched to prevent slips.

Any extra material that may be found to be necessary for embanking may be obtained from borrow-pits at points to be selected by the engineer, anywhere within a lead of..........chains from the centre of the bank under construction, or the engineer may order the slopes of the cuttings at certain places to be flattened so as to provide additional stuff.

The consolidation of the embankments must be effected by thorough trafficking when under construction, and rolling with a roller weighing not less than 150 lbs. to each inch of breadth. This rolling will be paid for by time at the rates scheduled. In addition to the provision just mentioned for consolidation, an allowance of 1 inch per foot of height of bank must be made for eventual subsidence.

Great care must be taken not to disturb any survey or level pegs or bench marks, and none of these are to be removed until the engineer or his representative shall approve of this being done. Where required "buoys" are to be left standing, with the turf undisturbed, to facilitate the measurements.

Every contractor must provide himself with the necessary appliances, such as spirit level, straight-edge, &c., to enable him to obtain accurate boning points from pegs or bench marks near his works.

Re-formation.—[Where the road to be metalled has been originally formed in earth, the following clause may be substituted for the one immediately preceding:—]

The formation to receive the metal must be brought into the shape shown by cross sections with good sound earth, and the whole must be well consolidated by rolling before any stone is spread thereon. On no account must stone be spread in mud or water, and every care must be taken to secure a solid bed for the metal. Watertables must be accurately graded according to longitudinal sections so as to secure proper drainage, and flanks neatly trimmed in accordance with drawings.

Subsoil Drainage.—Where the engineer considers that such are necessary, subsoil drains in accordance with following description and the sketch attached [To be as per Fig. 16] are to be constructed, and these will be paid for at the rate mentioned in the schedule. Three-inch agricultural drain pipes are to be laid with their ends abutting in trenches of the dimensions sketched, evenly graded with a fall of at least 2 inches, but not more than 1 foot per chain to an approved outfall. They are to be covered with 6 inches of clean, well-screened metal of 3-inch gauge, overlaid with a layer of 3 inches of finer metal or gravel of not more than 1½-inch gauge; thence to the formation level or subgrade the trench is to be filled with earth well consolidated.

Cross Drainage.—Where shown on plans, culverts are to be constructed of the types scheduled for the various points, and these will be paid for at scheduled rates. [These culverts will be built from type drawings prepared in accordance with the class of material available in the district in which the work is going on. See Chap. XV. for sketches and specifications.]

Metal.—[In districts where bluestone is not available, this clause must, of course, be varied.] The metal is to be of the best and hardest bluestone, equal to sample, free from honeycomb and all other defects, broken from spawls of proper dimensions in a crusher of approved type to 2½-inch gauge, and is to be properly screened, free from chips, small stuff, dust and dirt. Scabblings must not be used in the production of the metal. Not more than 10 per cent. of the stones must exceed 2½ inches in their largest dimension, and no stone must be larger than 3½-inch ring gauge. Proper screening will be absolutely insisted on.

Each tenderer is to send in with his offer a sample not less than 56 lbs. in weight of the broken metal he is prepared to supply. This will be, in the case of the successful tenderer, kept for comparison, and any metal not equal thereto will be absolutely rejected, and the Council will not be responsible for any loss of any kind that the contractor may suffer on account of the condemned material. [If no crusher is available the above must be altered accordingly to provide for hand breaking. See Chap. IX. as to gauge for various classes of stone.]

Delivery and Measurement.—The stone will be brought by rail to the......................Railway Station and carted out and spread by the contractor, it being distinctly understood that the Council accepts no responsibility for freight, demurrage, or railway charges of any kind, either on accepted or rejected material. Stone not up to specification will be rejected, and must not be carted out on the road.

The metal will be trimmed in the trucks by the contractor so as to be easily and accurately measured by the engineer or his representative before being unloaded, the contractor being present if he so desires. Payments will be made on truck measurement at the delivery station. The quantity to be spread will be............cubic yards per chain lineal, with a width of............feet as shown by drawings. Should the metal be brought by wagons or carts direct from the quarry to the road on which it is to be spread, measurements will be made in the vehicles used for its transport, which must be loaded uniformly by the contractor and examined and tallied in by the clerk of works before being tipped for spreading.

Spreading.—To ensure even spreading the metal is to be tipped on steel plates or board platforms and shovelled therefrom to the formation, care being taken to scatter the stones well in the process so as to secure an even crust of the thickness required. Before rolling, the metal is to be well assembled, any inequalities being evened up by the addition of fresh stone. For his own protection care must be taken by the contractor that the specified quantity of metal is not exceeded, as anything above that quantity, unless specially ordered in writing, will not be paid for.

Rolling.—When the metal has been spread as above it must be rolled as many traverses as the engineer may direct, using a roller weighing not less than 200 lbs. to each inch of breadth, any irregularities being made good as they appear by adding fresh metal from small heaps laid aside for the purpose. The roller must be horsed as per schedule with four heavy staunch draught horses, walking at the rate of not less than two miles per hour, and driven by a competent and able-bodied driver. After the rolling just described binding material will be spread as described in the next clause. After this, rolling will be continued when the road is, in the opinion of the engineer, in a suitable condition, until he considers that the metal has been sufficiently consolidated.

For the rolling of the metal the contractor will be paid at scheduled rates, with the proviso that he shall not be called upon to undertake rolling for any period less than half a day. From the completion of the work to the expiration of the maintenance period the contractor shall, on receipt of three days' notice from the engineer, again roll the road as before, the minimum period in this case being one full day. [Should the municipality own a steam roller it is generally better that the rolling be done by its own staff, in which case the above clause would be altered accordingly.]

Binding.—After the first rolling as described in the last clause, the contractor shall spread evenly on the metal............cubic yards of binding material per lineal chain of road. This material is to be [clayey, ferruginous sandstone to be obtained from the Council's quarry at............................] This must be excavated from the quarry by the contractor at his expense, as and where directed by the engineer, but no charge will be made for the material. It will be paid for at the rate scheduled, such charge to include all labour in getting, carting and spreading the material. Measurement will be made in the carts or wagons used to convey it from the quarry to the road. Until the expiration of the period of maintenance the contractor shall, if called upon by the engineer, spread fresh binding on the metalled surface, not less than 8 cubic yards to be ordered at one time during this period.

Maintenance.—The contractor is to keep the whole of the work in proper repair to the satisfaction of the engineer for two months from the date of completion, any ruts or inequalities that may appear being made good. Any binding added or rolling done on the order of the engineer will be paid for at scheduled rates, but all other expenses incurred by the contractor in maintenance must be considered to be included in the scheduled prices for the various classes of work. The deposit security, together with any charges for binding and rolling during the maintenance period, will be paid to the contractor when the engineer shall certify that the maintenance has been satisfactorily completed.

SCHEDULE.

o.	Quantities.	Description of Work.	Rate.	Amount.		
				£	s.	d.
1	40 chains	*Clearing of road complete, as specified, at per chain				
2	40 ,,	Formation of road, as per drawings, complete, as specified, at per chain				
3	100 lin. yds.	Subsoil drain complete, as specified, at per yard				
4	3 No.	Culverts, Type A, as per drawings, complete, at per culvert				
5	489 cub. yds.	Bluestone metal, 2½-inch gauge, provided and spread as specified, at per cubic yard				
6	10 days	Rolling, with driver, team of four horses and roller, as per specification, during construction of works and maintenance period, at per day of eight hours				
7	125 cub. yds.	Binding material, spread, complete, as specified, at per cubic yard ...				
8	5 days	Labourer in opening up, or any other work that may be ordered, at per day of eight hours				
9	Item	†Provision for extra work as per clause......of General Conditions		15	0	0

* If road has been previously cleared omit this item. † The amount will vary with the estimated cost, &c., of the works.

180. Cost of Telford Foundation.—This depends largely on the quality and size of the stones used. If the spalls are fairly regular in dimensions the laying and wedging is easy and the labour correspondingly light. Two men can set and wedge up about 2 sq. yds. 7 in. thick per hour when the stone has to be wheeled from the roadside; 7-in. pavement requires ¼ cubic yd. of spalls, measured loose, for every sq. yd., and the actual cost per square yard, exclusive of preparation of earth foundation, subject to the limitations mentioned in § 27, is about as given below:—

	s.	d.
Spalls, ¼ cubic yd., delivered on roadside at 3s. 6d. per cubic yd.	0	10½
Labour in setting, dressing, and wedging—one man for an hour	0	10½
Rolling	0	3
	2	0

181. **Cost of Rock Bottom Foundation.**—Assuming that spalls of a suitable size, requiring little breaking down, can be obtained without royalty charges within a mile of the works, the cost of 7-in. pavement course per square yard will, exclusive of preparation of earth foundation, be about as under:—

	s.	d.
Spalls, ¼ cubic yd., delivered on roadside at 2s. 6d.	0	7½
Labour in laying, spreading, &c.—one man, ¼ hour	0	2½
Rolling	0	3
	1	2

182. **Cost of Metal.**—The cost of quarrying, crushing, screening, &c., is considered in §§ 139 to 148, Chapter VIII., which see. Road metal is a regular market commodity in cities and large towns, prices being usually pretty well known. The figures given in § 148 are intended for use in estimating where reliable quotations cannot be got.

183. **Cost of Carting.**—The cost of transporting materials is fully discussed in §§ 12 and 13, Chapter II. Where the roads are fairly good, and the lead comparatively short, the cost will not be far short of 1s. per ton mile.

184. **Cost of Spreading.**—When the delivery by carts or wagons is fairly regular we have found that two vigorous experienced men can spread about 30 cubic yds. of broken stone from steel plates to a thickness of about 3 in. in the day of eight hours at a cost slightly under 6d. per cubic yd. Should the metal be spread one stone thick, the plates have to be moved oftener, and the surface covered is increased, so that each man cannot be relied upon to spread more than about 12 cubic yds. per day at a cost of about 8d. per cubic yd.

185. Cost of Steam Rolling.—The daily cost of running a 12-ton roller for 150 days per annum, where water can be obtained free of charge, is about as under:—

Engine driver	£0	10	0
Flagman	0	5	0
Quarter ton of coal at 25s.	0	6	3
Oil and waste	0	1	0
Interest 4½ %, depreciation 4 %, and repairs 4 %, say 10½ % on, say, £700	0	12	0
Total	£1	14	3

Under the item repairs is included the cost of replating the roller wheels from time to time, as described in § 110.

Road rolling cannot be completed in one operation; generally four or five visits will be necessary, depending on the material, and to a very large extent on the weather. As much as two hours may be spent in travelling to and from the engine shed and the works, another hour may be lost at odd times in taking in water, firing, &c., and the rolling time, allowing for further unavoidable delays, does not average more than five hours per day. Records kept by the authors, extending over a number of years, show that on the average about 55 cubic yds. of basalt per day can be fully consolidated by a 10-ton steam roller at a cost, allowing for interest, depreciation, and repairs on roller, of 7d. per cubic yd. On the assumption that each cubic yd. of 2½-in. gauge metal covers 24 sq. yds., the cost of rolling amounts to about 1-3d. per square yard.

186. Cost of Horse Rolling.—A 5-ton roller requires a team of four horses to haul it (see § 113), and the operating cost per day, inclusive of interest and repair charges, is about 27s. 6d. Not more than 30 cubic yds. can be rolled per day to a condition comparable with that resulting from the use of a steam roller, while the cost per cubic yd. is about 11d.

187. Cost of Binding.—The cost of binding is naturally very variable, but the average may be set down roughly at about 3s. per cubic yd. Metal screenings and dust cost about the same as the screened stone, the quantity required being as stated in § 177.

188. Cost of Street Construction.—The following is a typical detailed estimate of the cost per lineal chain of a 66-ft. town road, metalled full width to an average thickness of 5½ in., with a kerb, four-pitcher channels, and tar-paved footways similar to that shown in Fig. 60. The earthworks are very nearly balanced, that is to say, carting forward for considerable distances is not required. The figures are not of general application, but, subject to the limitations stated in § 27, will serve as a guide in the arrangement of estimates. It should be mentioned that only very rarely are the whole of the improvements set down undertaken at once, and that in the first instance the outlay is very much curtailed.

ESTIMATE.

Earthwork in formation of road, channels, and paths—60 cub. yds. of excavation at 1s. 3d...	£3	15	0
Rolling the roadbed prior to metalling	0	4	0
2½″ bluestone metal (loose) in railway trucks—53 cub. yds. at 6s.	15	18	0
Carting one mile from railway station—53 cub. yds. at 1s.	2	13	0
Spreading and assembling metal—53 cub. yds. at 6d....	1	6	6
Binding, delivered and spread—10 cub. yds. at 3s. ...	1	10	0
Steam rolling—53 cub. yds. at 7d.	1	10	11
12″ bluestone kerb—132 lin. ft. at 2s. 6d.	16	10	0
Channelling—44 sq. yds. of pitching complete, at 3s. 6d.	7	14	0
Tar pavement, as per specimen, § 288—161⅛ sq. yds. at 1s. 10d.	14	15	10
Contingencies, engineering, &c., 10 % on above, say ...	6	11	0
Estimated total cost per chain, including engineering charges and an allowance for contingencies	£72	8	3

It will be noted that the cost per lineal ft. works out at about 21s. 6d.

In the common case of a street metalled 5 in. thick for 16 ft. in the centre, with two rows of three pitcher channels, but no kerb, and with neatly-trimmed earth paths, the cost in average cases is about 6s. to 6s. 6d. per lineal ft. complete.

189. Sea Walls.—The design of walls to resist wave action and to support embanked roadways at the same time is too large and difficult a subject to be entered upon at great length in these pages. Conditions vary so widely that general principles only can be discussed. It is always to be remembered that the principal weakness of most sea structures, especially those directly opposed to the action of waves, lies in the liability of the foundation to wash out. The proper course is to carry the footings well down, and this point cannot be too strongly insisted on. The profile of the wall should, of course, be such as to break up the waves with the minimum of effect on the foundations, and without causing undue "run up."

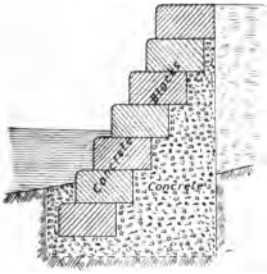


Fig. 76.
Stepped Profile Sea Wall.

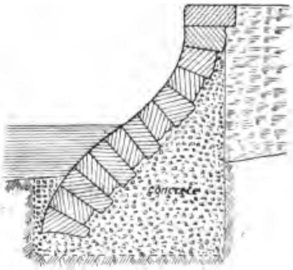


Fig. 76a.
Ogee Profile Sea Wall.

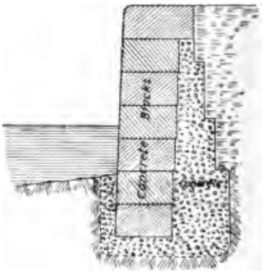


Fig. 76b.
Vertical Profile Sea Wall.

Practice on this point is very diverse, but walls built in steps, as shown in Fig. 76, are believed by many engineers to accomplish this object better than any other form. Steps we believe to be an improvement on a sloping wall with a plane face, as by breaking up the waves they reduce the volume of water likely to be thrown on to the roadway.

The Ogee profile shown in Fig. 76a looks well, but is less effective in breaking up the waves, is more troublesome to construct, and, presenting as it does a concave face to the shock, is not so strong as either a vertical or a stepped wall. Moreover, it has been noticed that in certain cases the ogee form induces more scour at the toe than the other forms.

A vertical, or nearly vertical, face, such as is shown in Fig. 76b, can be recommended in situations open to really heavy seas. In cases where the wave action is less, as on the shores of large bays like Port Phillip, we prefer stepped walls to any other type. We consider that, generally, vertical and stepped walls are superior to sloping and curved ones, but seeing that in all cases there is bound to be scour at the toe, we would again urge the absolute necessity for making the foundations amply deep, and where possible we would protect them by large rubble of high specific gravity.

CHAPTER X.

MAINTENANCE OF METALLED ROADS.

190. There has been noticed in the past a praiseworthy desire on the part of municipalities and Government Departments to extend the construction of metalled roads whenever funds permitted. It is, however, a matter of regret that such roads when once constructed have in too many instances been starved for the sake of a sufficient annual vote to provide for reasonable maintenance. The result is that many well-designed and well-built roads have fallen into a hopeless state of disrepair, so much so, in fact, that nothing short of reconstruction will suffice. While it is admittedly poor economy to neglect repairs to roads of any sort, metalled roads in particular should never be allowed to fall into bad order, because the cost of restoration is for them so much greater than for earth or gravel roads. With roads built of a sufficient thickness to carry heavy loads without breaking up, wear is confined to the surface coating of metal, and maintenance is to a large extent a question of replacing worn-out material; so that, assuming equally good construction, the cost of maintenance depends largely on the quality of the stone used. In addition to metalling there are other works, such as trimming of shoulders, cleansing of watertables, and repairs to structures, practically independent of the wear of the broken stone, which must receive their full measure of attention. Maintenance has too often been entrusted to incompetent foremen and others possessing no real knowledge of their work, and quite ignorant of the principles of road-making. The construction and maintenance of roads require just as much technical knowledge and skill as railway or bridge building, and should be supervised by men well trained to the work.

191. Effect of Climate on Roads.—Highways are fully exposed to the rigours of weather, more so indeed than any other engineering structure. It may safely be stated that the combined influence of rainfall, winds, and changes of temperature has a destructive effect on many Australasian country roads almost equal to that of wheels and horses' feet.

(a) *Rainfall.*—Where rain falls gently, as it generally does in Europe, the scouring effect on roads is but trifling. When, however, the fall is torrential, with 2 in. or 3 in. in the hour, as is often the case in this continent, roads suffer most severely from erosion, so much so that deep ruts are frequently scoured out by a single shower. The presence of just enough water to keep the surface moist, but not springy, is desirable. Water lying in ruts softens the surface, and causes rapid wear under traffic.

(b) *Drought and Wind.*—The effect of long-continued dry weather is to reduce the cohesion of the road surface by drying out moisture, which in some cases is the only bond holding together the various materials. As a general proposition there is no doubt that metalled roads wear faster when dry than when slightly moist. Strong winds blow away the binding material and the protective covering of dust, creating at the same time an intolerable nuisance. The hot and very dry winds so prevalent in parts of Australasia largely increase the cost of maintenance. The authors have found that roads whose direction is the same as that of the prevailing summer winds, or nearly so, suffer much more therefrom than do roads across which those winds blow.

(c) *Frost.*—In the mild climates of Australasia freezing of the soil to any depth is rare, and the ill effects of frost are but little felt. In a few of the cold mountain districts frost penetrates to some feet, and the result is that the moisture in the ground is converted into ice. Water expands when frozen, and if the road is saturated, upheaval and disintegration result. The only remedy, and it is a thorough one, is to keep the foundation free from moisture by preventing the soakage of water from above, and by lowering the water level by subdrainage, as recommended in § 70.

192. Effect of Traffic on Roads.—

(1) *Hammering of Horses' Feet.*—Sir John MacNeill estimated the wear due to horses' feet as three times greater than that directly attributable to abrasion by wheels. Caulks on shoes loosen stones, more especially when ascending or descending steep grades with heavily laden vehicles. Ravel-

ling of the surface due to this cause is most noticeable in dry weather, and can be best cured by the addition of a thin coat of suitable binding, as recommended in § 202.

(2) *Abrasion by Wheels.*—The action of wheels in cracking and grinding up stones is greatest where the metal is loose, and when the surface is covered with brittle material such as quartz. The best remedies are to keep the surface smooth, to provide wide tires, and to limit the loading on vehicles having narrow ones. Two-wheeled vehicles injure a road more than four-wheelers carrying the same load; this is accounted for by the twisting motion of the former. Great damage to the edges of metalled strips results from the action of some drivers, who on down grades run their vehicles so that one wheel, or pair of wheels, is just off the metal. The object is to utilise the resistance of the softer flanks in steadying the increasing momentum, as being less troublesome than to apply the brakes.

(3) *Breaking Through.*—Whenever the metal fractures and breaks through, the road is obviously too weak to withstand the traffic passing over it. The cause may be excessive loads on narrow tires, deficient thickness of metal, or a poor foundation. It is generally necessary to strengthen the road by recoating with the best stone obtainable at reasonable cost.

(4) *Rutting.*—Horses invariably display a tendency to follow the track taken by preceding vehicles. The effect of this, especially in country districts where traps pass each other but seldom, is to form ruts partly by abrasion and partly by the extra consolidation due to wheels constantly running over the same lines. Rutting is not so noticeable where there is considerable traffic, and where vehicles in passing are compelled to take the sides of the road. Much damage to roads would be avoided if drivers would vary their tracks slightly. When ruts are once formed, water lodging in them cannot run off transversely, no matter how great the crown; the surface becomes soft through saturation, and the wear is more rapid than if the road were moderately dry. Ruts appearing in newly-spread metal should generally be raked in and rolled as soon as they appear, though in some cases further rolling

will obliterate all traces of rutting if done during, or immediately after, heavy rain. Ruts should never be filled with earth, screenings or stone appreciably softer or harder than the metal composing the wearing coat.

(5) *Grippers on Traction Engines.*—Diagonal bars on the driving wheels, or "grippers," as they are sometimes termed, are an undoubted source of serious damage to all sorts of roads, and something less destructive should be insisted on. New bars are more destructive than old ones, the arrises of which have been rounded off by use. Numerous attempts have been made to devise an improved tire, and Boulton's flexible wheel is as successful as any. They have not come into use in Australasia, and their existence is but little known; they have, however, been taken up in England with success. Hardwood blocks, with the grain radially fitted into cells in the periphery of the wheel, and loosely secured by bolts, are seated on rubber cushions about an inch thick to absorb the jar. The weight of the traction engine is supported by three or four of the blocks, which adapt themselves to the road. By them the load is distributed over such a large area that the pressure on the road surface in the case of a 12-ton traction engine is only a little over half a cwt. per square inch, while the tractive efficiency is much higher than with ordinary wheels fitted with gripping bars.

(6) *Equal Length of Axles.*— As usually built, the axles of four-wheelers are of equal length, so that the rear wheels run directly behind those in front. If the hind axle were a little the longer, damage to roads would be minimised, but, unfortunately, the draught would be increased on soft and muddy roads. Then, again, vehicles could not travel along steel plate trackways, of which we have some miles already laid in this country. For these practical reasons it has become the custom to make both axles of the same length.

(7) *Motor Cars.*— With the last few years motor vehicles have become popular, and at the same time a source of anxiety to engineers having macadam roads in their charge. The effect of the high velocity and heavy weights of motors is partly to abrade the surface as does an ordinary wheel, and

partly by suction to withdraw the fine binding material from the road, raising a great deal of dust, and actually loosening the surface where the cars are numerous. Heavy high-speed cars do most damage. Some of the appliances attached to motors, including armoured and chain tires, are very destructive to roads, and their use should not be permitted. In Chicago the boulevards are continually under repair on account of oval depressions, which are attributed solely to motor traffic. We have found that metalled roads, tarred as recommended in § 213, and having a hard skin, are proof against damage of this sort, and our observations are confirmed by reports from England, France, and America. Motors travelling over ordinary metalled roads faster than 20 miles an hour create an intolerable dust, and, for this reason alone, some restriction of speed should be enforced. For further information on the subject, see Chapter XIII.

193. **Wear of Metalled Roads.**—The thickness of material worn, blown, or washed away each year depends on the traffic and the quality of the metal, as well as on the design, construction, and climatic conditions. Paradoxical as it may appear, it is nevertheless true that metalled roads last longer under moderate traffic than if wholly disused. The effect of traffic in wearing away the metal is to create stone dust, which replaces binding material removed from time to time by wind and rain. If the vehicles using a road are so few in number as to furnish little or no dust by abrasion, the stones soon become exposed and loose enough to be dislodged by the lightest traffic.

194. **Volume of Traffic.**—For purposes of comparison of the relative durability of road materials, it is desirable to establish records of the nature and volume of traffic in the cities and the larger towns. A mere count of the vehicles and horses using any particular street is of little service, and statistics, to be of real value, must include in addition an estimate of the number of tons per annum passing over the generally travelled surface per yard in width. Up to the present very little information has been published on the subject dealing with Australasian conditions. The only recorded sets of observations we have heard of were made in Sydney

by Mr. A. C. Mountain, M. Inst. C.E. Two of these, together with a few English and Canadian observations, are tabulated below:—

TABLE XIV.

Locality and Year.	Average Number of Vehicles per Day.	Average Number of Horses per Day.	Tons Annually per Yard in Width.
* George-street, Sydney, near Town Hall, 1886	10,960	19,776	246,427
* Oxford-street, Sydney, corner of College-street, 1886 ..	3,171	4,016	99.981
† Euston-road, London, 1895..	..	..	575,544
‡ Montreal, Canada, 25 Sts., 1892	..	..	15,000 to 120,000 between 7 a.m. and 6 p.m.

* Paper by Mr. A. C. Mountain, Min. Proc. Inst. C.E., Vol. XCIII.
† "Road Making and Maintenance," by Thos. Aitken, 1907, p. 417.
‡ Compiled from data in Report of City Engineer, 1893.

Unfortunately, statistics for towns of moderate size are not yet available. Further particulars, with full details of the nature of traffic, class of road, and estimated annual wear, would be very useful if tabulated like the Sydney observations. It must be remembered that heavy lorries, especially those with wheels of small diameter and unprovided with springs, are more destructive than light vehicles conveying the same tonnage in smaller loads. Personal observation and published statistics lead us to believe that 1 cubic yard of average quality basalt is required per annum per mile for every 80 tons per yard in width when the traffic is moderately heavy. The figures are approximate, but may serve as a rough guide until more definite information is available, and as a basis for future observation.

195. **Systems of Maintenance.**—There is great diversity of opinion as regards maintenance methods. Some engineers insist on patching or darning as wear becomes apparent, others prefer to recoat long stretches rather than one hole after another. The advocates of patching contend that roads require constant attention, and that it is bad practice to neglect the surface until it is practically worn through, claiming at the same time that theirs is the cheaper method. There are, how-

ever, several weighty objections to maintenance by patching, the more important of which, briefly stated, are as follows:—

(a) Patched roads do not present as even and regular surfaces as they should. It is well known how extremely difficult it is to prevent the ordinary roadman from making his patches 3 in. or so higher than the surrounding surface, and how quickly wheels, falling from the mounds so created, make holes on each side of them, causing the road to be worse for patching.

(b) Under the system of continuous repair, the mending of a road is never completed; loose metal seems to be ever present in one place or another, to the discomfort of the travellers, and to the injury of their horses and vehicles.

(c) The use of modern scarifiers for loosening the old surface is practically out of the question in disjointed work, and hand picking must be resorted to.

(d) Complete rolling of patches of new metal is about twice as expensive, and consolidation is of necessity accomplished by the primitive method of forcing traffic on to loose stones.

(e) Less metal is needed where roads are maintained by sheeting than by patching worked in by vehicular traffic. Aitken* considers that under English conditions a saving of 25 per cent. is effected. In Australasia we think that 25 per cent. in cool, moist districts, to 35 per cent. in hot, dry climates, should be allowed. The patching system is, moreover, expensive, in that the same supervision cannot be given to labourers working in twos and threes as to gangs of eight or ten men. In the event of a road breaking through under extremely heavy loads or under other exceptional circumstances, patching must be resorted to, to bridge over the period until the next metalling season, but generally it will be found better to follow the system lately adopted throughout France and resheet roads in long lengths. Till two or three inches of the crust is worn off, a well-constructed metalled road usually remains pretty smooth and even. The system that is recommended provides for the sheeting of a road whenever the wear amounts to about 2 or 3 in., or perhaps a little more, if the surface is still smooth. To postpone repairs until too much is worn off is bad policy, as the road is by that time in such a rough state as to be objectionable. As a matter of fact, the chief argument advanced against the system is that repairs are so often neglected till the road is almost worn out. We must not forget that this depends largely on the coat of metal applied; if a thick coat, say 6 in., is put on, and when 2 in. are worn off the rest is scarified, there will be waste of effort and material, so that we must decide on the thickness before deciding on the wear we will allow before recoating.

---

* "Road Making and Maintenance," 1907, p. 287.

196. **When to Repair Roads.**—Repairs to macadam roads should in the average Australian climate be confined to the cooler months, April to October, when showery weather may be expected. In very wet districts, November and December are the months. Repairs can, with the aid of a steam roller, be carried out during hot weather, but not to the best advantage, either as to cost or result, and only with the assistance of water artificially applied in liberal quantities. Where horse rollers only are available, sheeting should not be attempted between November and March, as without the very best appliances, binding of the road cannot be expected when evaporation is at a maximum. Employment can be found in summer for the permanent staff of most municipalities at work suited to the season, including tar pavement, tarring roads and gutters, tar macadamising, watering streets and trees, and general repairs to plant and structures.

197. **Loosening the Surface.**—Although a deeply-rooted impression prevails that the foundation of a road should never be broken into, it is quite impracticable to expect a coating of newly-applied metal to knit and bond with a hard road surface, so that the latter must be loosened to the depth of an inch or

so. If this precaution is neglected, quite a large proportion of the new stones will be cracked in a futile attempt to roll the metal into the hard surface beneath. Further, if the crust is not loosened, the coating is very liable to flake off, under traffic or the influence of frosts, after it has been worn down to a thickness of 2 in. or so. A too common practice is to score grooves in the old metal by hand picking across the road and about a foot apart. While this is perhaps better than no loosening at all, the results are anything but good, as ridges and hollows nearly always appear when a road so prepared becomes nearly worn out. What is wanted is a loosening of the old road, not necessarily to a uniform depth below the worn surface, but to such varying depths as will leave the solid base beneath parallel to the new grade of the road. The object is to secure equal settlement during consolidation, which, it must never be forgotten, continues under traffic for a long time after ample rolling is completed. Loosening is best done with one of the types of scarifier described and illustrated in Chapter VII. Metalling can be broken up by a steam roller provided with picking spikes in the rear wheels, but not so effectually and cheaply as by a scarifier. The use of spikes is so severe on the engine that their use cannot be recommended. In the absence of a steam roller certain types of scarifier (see Chapter VII.) can be drawn by traction engines, with good results. The relative costs of scarifying and hand picking are discussed in §§ 120 and 121. Ploughs are not suitable for this work, and should never be used on a road that is to be recoated. It is most important to have any considerable quantities of loose mud or dust removed from the surface by scraping or sweeping before the crust is loosened. In this connection, however, we must say that the roads should never be allowed to attain this condition.

198. Size of Maintenance Metal.—As stated in § 168, finely-broken metal, unless extremely hard and tough, makes a weak road that wears out quickly and breaks up under heavy traffic, while too coarse stones make a rough, noisy road, from which the larger pieces are easily dislodged. For general repair purposes, the gauges should vary between 2½ in. for moderately hard basalt, to 1½ in. in the case of the hardest diabase rock.

199. **Thickness of Coat.**—As already stated, it has been found better to apply sheets of metal about 3 in. thick when a road has worn down to that extent in preference to thicker coatings at longer intervals. In average cases each cubic yard of 2½-in. metal will resheet 11 to 12 square yards.

200. **Spreading.**—After the scarifying or picking is completed, the loosened material should be scraped into shape with rakes, road machines, or harrows before the new metal is spread. The smaller stones dislodged by the scarifier should be raked to the sides, but should not be raised in the centre. Spreading should be from plates in the manner recommended in § 171.

201. **Binding and Rolling.**—Except that rather less binding is required in a thin sheet of metal, the rules laid down in the preceding chapter may be followed in their entirety.

202. **Ravelling of Newly-Sheeted Roads.**—When an imperfectly consolidated road shows signs of breaking up in the summer under the action of horses' feet, we have found that a light coat of good binding watered once or twice, preferably towards evening, generally effectually checks the ravelling.

203. **Trimming Flanks.**—From time to time it is necessary to trim the unmetalled flanks of roads by removing the detritus which accumulates principally from the washings of the road. This is usually undertaken at the same time as the channels are cleansed of weeds, and earth paths reshaped and dressed up. In towns and suburbs trimming is usually undertaken by hand, and should when possible be started before the winter. Owing to the hardness of the ground it is not always possible to start the work in the autumn, in which case it is best left till the late winter or early spring. If deferred too late in the season, dust arising from the recently-trimmed portions is liable to be objectionable. For this reason it is not advisable to attempt to keep the flanks free from grass, and in most situations grassy sides are rather an advantage than otherwise. In country roads trimming can, to a large extent, be carried out by road machines or drag scrapers described elsewhere in this volume. In Fig. 77 is shown a view of Hogg's patent road-paring

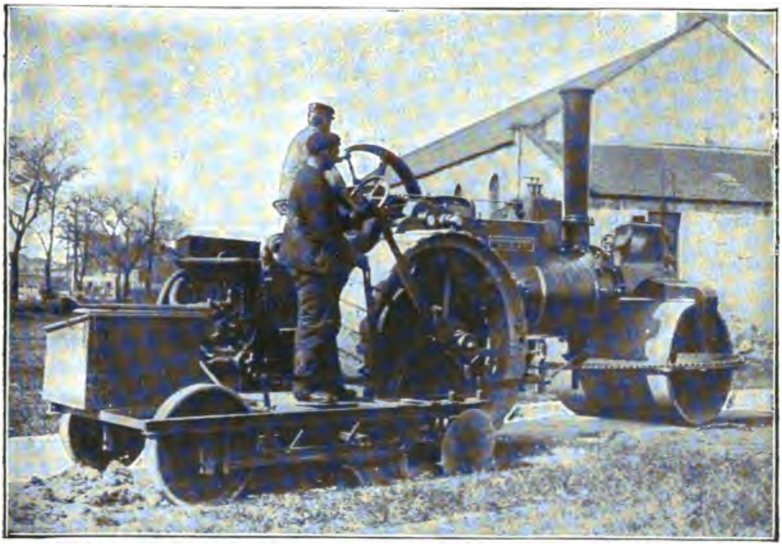


Fig. 77.
Hogg's Patent Road-paring Machine.

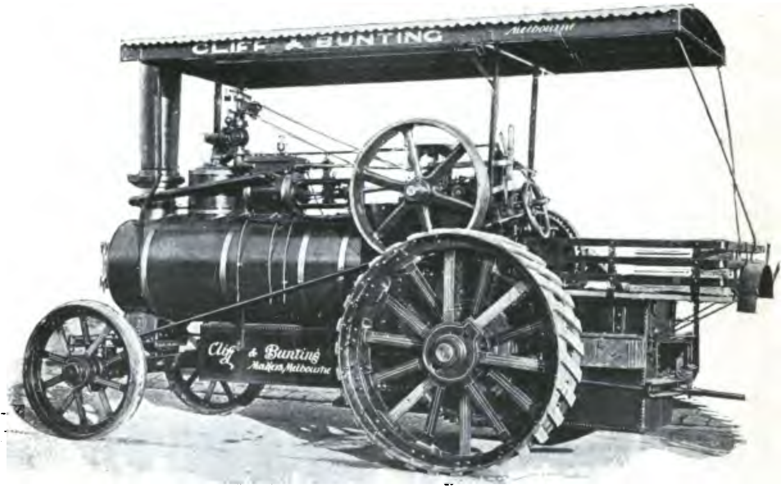


Fig. 78.
First Australian-made Traction Engine.

To face p. 198.

To face p. 199.

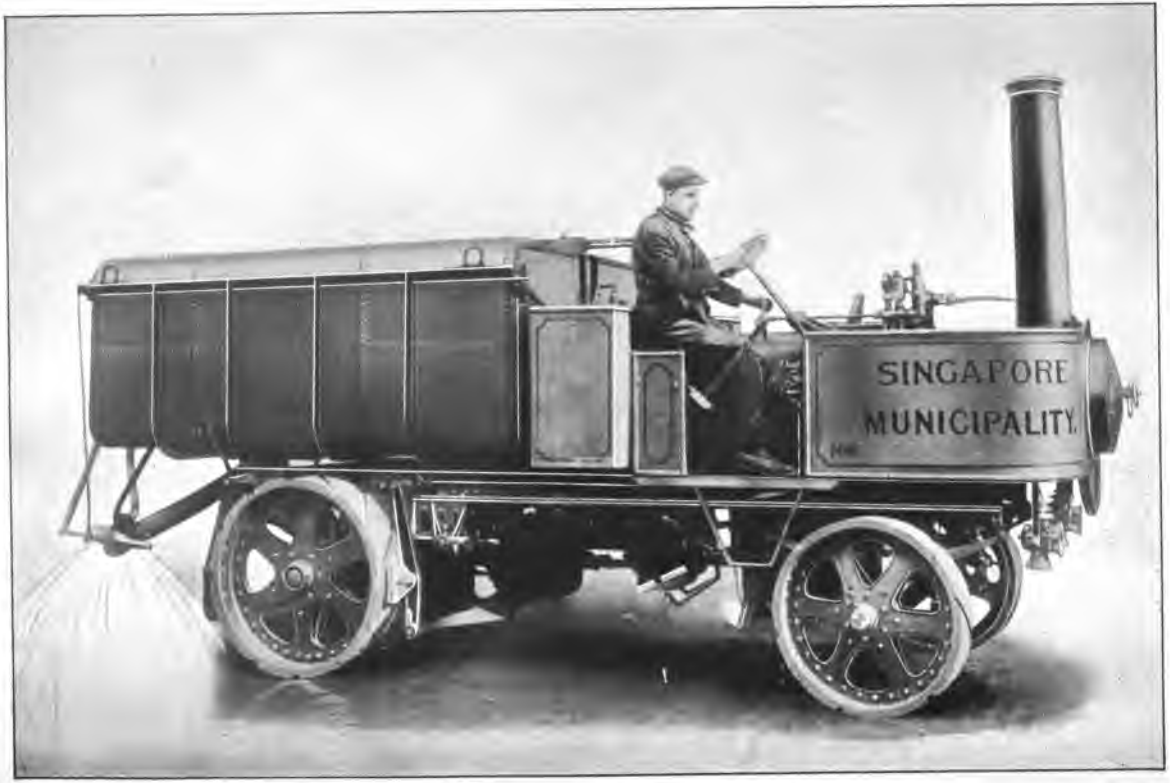


Fig. 79.—Thornycroft-Stewart Steam Van, with Water Tank.

machine manufactured by John Fowler and Co., of Leeds. This useful labour-saving appliance can be readily attached to, and detached from, any steam roller or traction engine, and with it both sides of a country road can be pared at the trifling cost of about 15s. per mile under Australasian conditions. The machine cuts a track up to 2 ft. 6 in. wide, and any depth not exceeding 10 in., even in moderately stony ground, or through moderately large roots, and can be lifted clear of obstructions by the one man required to operate it. The cutting discs and share cutters are of special steel, and the revolving cutter on the hind axle leaves the lifted turf in a continuous heap ready for removal. The cost of this effective appliance is about £90 in England. Fig. 78 shows a view of the first Australian-made traction engine by Messrs. Cliff and Bunting, of North Melbourne, and which is reported to be working with the utmost satisfaction.

204. **Sweeping Machines.**—Horse-sweeping machines are constructed with a wrought-iron frame, iron wheels, and wooden shafts for one horse. The brush, to which motion is imparted by a chain belt from the axle, is mounted obliquely to the direction of travel, and being about 7 ft. long sweeps a track nearly 6 ft. in width. A seat is provided for the driver, who, by levers within reach, can raise and lower the brush without stopping the horse. Sweeping machines cost about £42, and to refill a set of stocks costs about £2 10s.

These machines are indispensable for sweeping city pavements in the early mornings. On macadamised roads horse-sweepers are useful for removing semi-liquid slush and for cleaning off dry dust; they do not work well on half-dry mud, and should never be used when the surface is in this condition. For cleaning up a road prior to tarring the surface, mechanical sweepers of this description are most useful. The surface that can be swept per day varies with conditions, but averages about 25,000 square yards. Hand-sweeping machines are in common use in England for odd jobs, but are little known here.

205. **Water Carts.**—Street watering carts are of various types. Those drawn by horses generally consist of a high four-wheeled vehicle with broad tires, on which a 400-gallon

tank is mounted. The water may be sprinkled from holes pierced in the rose, or it may be distributed by rotary discs driven off the axle. In the first arrangement the water is spread by gravity over a strip 20 to 22 ft. wide; with the second appliance, invented many years ago and now being largely used, nearly 30 ft. can be covered. The disadvantage pertaining to the use of these vehicles is the considerably-increased draught required on account of the power required to drive the disc. For wood-paved streets side delivery carts are used to flush the pitched flanks and channels with a dilute disinfectant. The ordinary cart with tank and rose costs from £50 to £60 in Australia.

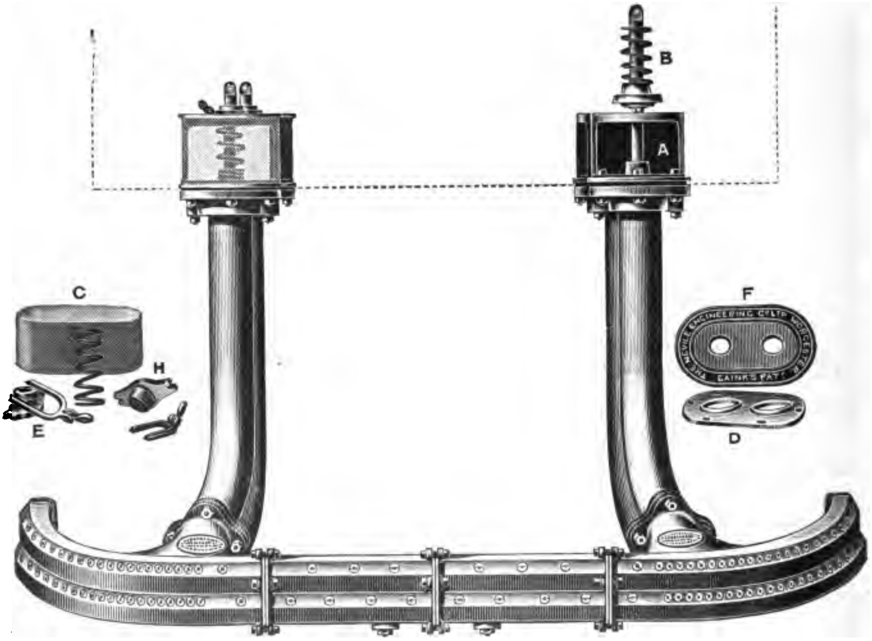


Fig. 80.

Caink's Patent Jets and Sprinklers.

Motor water vans have lately come into use in up-to-date cities. Fig. 79 illustrates a 5-ton steam wagon made by D. Stewart and Co. Limited, of Glasgow, in which the water tank is interchangeable with an end tip body that is used for transporting refuse, road metal, &c., when the vehicle is not in use as a water van.

A defect in the ordinary water cart is undoubtedly the absence of any satisfactory arrangement for regulating the amount of water discharged over the surface. The difficulty is claimed to have been practically overcome in Caink's patent jets and sprinklers, made by the Nevile Engineering Co. Limited, of Worcester, in which mechanical movements for regulating the distribution of water are eliminated. In this device, shown in Fig. 80, the cast-iron distributing pipe is fitted in the larger sizes with a double row of jets, each of which breaks the falling water into a fan-like spray that does not wash out the surface. The jets of the top row give a fine spray, those of the bottom a medium, and both together a heavy spray. Each side can be worked independently, and the whole is controlled by four valves at **B**, working in the casing **A**, and operated by a simple but ingenious treadle gear at the driver's feet. **C** is a perforated strainer, **D** brass seating, **E** is cam lever and fork, **F** cover, and **H** cross bar.

The jets are made in a variety of sizes, and are interchangeable. The down pipes are coupled to the tank and to the distributor by flexible compression joints, which enable the parts to be easily fitted to existing water carts by any competent mechanic. The price of the sprinkler with double row of jets controlled by four valves, with treadles, &c., complete, is £15 in England; those with a single row and three valves to enable the middle or either side to be watered independently £11, or £9 10s. if with two valves only.

206. Sweeping and Watering Machine.—The combination of street sweeping and flushing vehicles constitutes a decided improvement in machinery for street scavenging. The wagon illustrated in Fig. 79 can be utilised as such by arranging the water distributing discs in front of the motor and connecting them to the tank by a hose of large diameter. A power-driven revolving brush, similar to that used on an ordinary horse sweeper, is attached to the rear of the wagon, and sweeps the already sprinkled road without raising dust.

207. Combination Sweeping Machines.—Machines which will combine the operation of sweeping the roadway and lifting the detritus into a receptacle on a wagon have long been sought as being the most sanitary means of scavenging.

The Melbourne City Council is importing some of Whittome's machines, with a view to picking up the sweepings as they are collected, and as this class of machinery is still in the experimental stage, the result will be watched with considerable interest.

208. Scraping Machines.—The type of horse street-scraper manufactured in Australia is made with angle iron frames, iron wheels, and wooden shafts for one horse. The scraping shoes are of cast iron, and can be cheaply replaced when worn. The scraper can be raised and lowered by a lever from the driver's seat. The cost in Australia of a new machine, that will scrape a track about 5 ft. wide, is approximately £30. Scrapers are used to remove sticky mud, and may be relied upon to clean up about 20,000 square yards per day. Scrapers loosen the stones if the surface is at all irregular, and are consequently destructive to metalled roads. They are very useful machines, but should be reserved for special cases; cleansing is nearly always better and more economically done by sweeping machines.

209. Scavengers' Brooms.—The best pure Bahia bass brooms are the most economical that can be bought. A suitable size has 16 in. x 4 in. stocks, with bass 7 in. long, showing 6 in., and sixteen by four knots. The cost of these is about 27s. 6d. per dozen, and each one will on the average last a man about six or seven working days when engaged practically full time as a scavenger.

210. Tumbler and Garbage Carts.—For carrying slush, gutter sweepings, and objectionable refuse that would leak out of an ordinary dray, iron tumbler carts are useful. The cart is filled from the rear, and is fitted with a self-tipping arrangement, whereby, when a bolt is drawn and the horse slightly backed, the tank turns over and discharges its contents. Two-wheeled carts of this description are made to hold. about 200 gallons of liquid, or about 1 1-3 cubic yards, of refuse, and cost about £35 complete.

The bodies of all drays or wagons used in the collection of garbage should be mounted as low as possible, so as to minimise the quantity of dust blown from the scavengers' shovel when loading. For similar reasons, the vehicles should be covered as far as possible. The most recent designs are provided with a single trap door and a well-fitting cover on top.

211. Total Cost of Maintenance.—Systematic records of the cost of maintaining streets and roads are seldom kept and rarely published. Even when figures bearing on the subject are issued, there is generally an element of doubt as to the scope of the works included. To be of real value cost data must state precisely whether scavenging, repairs to footpaths, &c., are included, or whether the figures refer to the bare cost of metalling the carriage way. Conditions vary so widely that estimates are liable to be misleading. French national roads, metalled 20 ft. wide, and subjected to heavy traffic, cost £51 per mile per annum to maintain, while secondary roads cost about £35 per mile. Metalled roads in country districts in Australasia carrying moderate traffic can be maintained in good order for £35 per mile, those carrying very light traffic for as low as £10, if substantially constructed in the first instance. In suburban or country town streets the cost ranges between £40 and £100. In large cities the expenditure may exceed £300, in which case, as pointed out in § 18, they should no longer remain as metalled roads, but should be paved with more durable materials.

The most satisfactory method of arriving at the probable cost is to estimate, on the basis of the quantity of metal required, the wages of the necessary labourers and other incidental expenses.

212. Maintenance by Contract.—A few municipalities adhere to the old system of letting contracts for the maintenance and scavenging of their roads. From their experience of both systems, the authors are convinced that ratepayers are best served when such work is carried out by administration through a capable clerk of works under the direction of the engineer. It is almost impossible to keep most contractors up to the specification in contracts of this kind, as the difficulties of supervision are so great. When daily-paid labourers are assigned areas and held responsible for their cleanliness, we have found little difficulty in securing efficient scavenging.

213. Tarring the Surface of Metalled Roads.—Tarring metalled roads with the object of preserving them from decay, and incidentally preventing the formation of dust, has passed through its experimental stages, and may now, under favourable conditions, be accepted as a thoroughly practical solution of a difficult problem. To French road engineers credit is due for first recognising the merits of tar for this purpose. The authors have so treated many miles of streets, and have found that where good tar can be had at a moderate price, excellent results can be obtained, provided that certain fundamental principles, discussed below, are closely followed.

In the first place, the average road is not in a fit condition to receive tar. Only smooth, well-drained, and well-consolidated surfaces are suitable. If uneven, cuppy, or too flat roads are tar painted, the result is sure to be disappointing, as the tar invariably perishes, and wears to a really objectionable slush when submerged for any length of time in pools of water. The same result has been noticed with asphaltum pavements, even with those of the highest quality. It is hopeless to expect good results from tar painting on newly-constructed streets liable to further subsidence and compression, or on roads with any but smooth surfaces. A road worn just enough to be at its smoothest is the best, and our experience is that streets subjected to moderately heavy suburban traffic are most likely to be in that condition about fifteen months, the next summer but one, after resheeting.

214. Quality of Tar.—As is well known, the quality of coal tar is variable, much depending on the degree of refinement in manufacture at the gas works. The best tar is thick and jet black; that of an inferior quality, containing water and an insufficiency of pitch, is oily and of a brownish hue. For general road and pavement works, tar should contain practically no water nor less than 55 per cent. of pitch. The authors have been able to purchase undistilled tar in bulk, containing on analysis:—

Ammonia liquor (containing 5 ozs. of .880 ammonia)...	4	gals.	per 100 gals.
Naphtha ...	3	,,	,,
Light oils	6	,,	,,
Carbolic and Cresote oils	23	,,	,,
Anthracene oils...	22½	,,	,,
Pitch, by weight	550	lbs.	,,

and have found that, although good results can be secured by its use when applied hot, the percentage of volatile constituents is high. Distilling plants have been installed in several cities in these States, including Melbourne, Sydney, Prahran and Collingwood, and by a few of the gas works.

In Melbourne* the distillation of 90,750 gallons of crude tar produced 80,657 gallons of refined tar, at a cost of £292 12s. 9d. Revenue derived from the sales of by-products nearly equalled the cost of distilling. Ammonia liquor has as yet no commercial value, but naphtha is worth 1s. and tar oils 7½d. to 9d. per gallon. The light oils yield phenyle, worth about 2s. per gallon, as well as napthalene salts, used as a base for a strong disinfecting powder, and worth about £10 per ton.

In the Sydney† plant, distillation is not carried so far. There the tar is boiled for five or six hours, during which time the 6 to 8 per cent. of water present is distilled off. It is then boiled for another two hours, when a further 1½ per cent. of the total bulk in the form of the first light oils are obtained. The tar at this stage is run into tanks for use as required.

It is now recognised that over-distillation is a mistake; the whole of the water should be driven off, but only a proportion of the contained oils should be expelled, otherwise the tar loses its elasticity, and, becoming brittle, tends to peel off. Many contend, and we think reasonably, that it pays best to use hot tar in crude form, provided that there is little or no water present.

215. **Applying the Tar.**—The work must be done in summer when the road is dry and in a condition to absorb the tar; warm sunny days should be chosen, and tarring must cease if the air turns cold or damp. The surface, which, as already stated, must be smooth, is swept clean with hand or horse-driven bass brooms before the tar is applied; wire brooms, being too stiff, are unsatisfactory. In this country the tar is usually brought to the road in a tank mounted on a dray fitted with a grate beneath, in which a small fire is kept

---

* Report by Mr. A. C. Mountain, M. Inst. C.E., for 1904.

† Report by Mr. W. M. Gordon, City Surveyor, for 1904.

burning so as to maintain the liquid at a temperature of about 170 deg. F. It is distributed on the centre of the road direct from the tank tap or from watering cans. The tar is spread and brushed in with stiff bass brooms, after which it is, if practicable, allowed to soak in for three or four hours. The longer the soaking process is continued the better the result, the time being limited by the inconvenience that may be caused to traffic. Care must be taken to apply a very light coating of tar, or the result will be unsatisfactory. The difficulty with hand painting is to secure a thin application, and for this reason the viscosity of the tar has to be reduced by heating. Penetration by the tar through the joints in the metalling to a depth of ¾ in. to 1¼ in. is not uncommon. The operation is completed by sprinkling a coat of road dust, or sand, sufficient to prevent the tar from being picked up by wheels.

We have found road, not gutter, sweepings or coarse toppings superior to sand, especially if the latter contains salt. Light debris, such as particles of leaves, chaff, &c., make no practical difference, as when the sweepings are being spread the heavier particles fall first; and the rubbish lying on top is generally blown away without being incorporated with the tar coat. If the dust or sand is spread too freely the coat is apt to flake off; not more than just enough to dry the unabsorbed liquid should be applied. If tar is to be used on an extensive scale, it must be applied by machinery.

216. **Tar-Spraying Machinery.**—As will be seen by reference to Table XV., labour charges are high when the tar is applied by hand. To reduce the cost of application, and to effect economies in the quantity of tar spread, several tar-spraying machines have been placed on the market. The appliance awarded first prize in the competition of 1907 conducted by the British Roads Improvement Association is that patented by Mr. Thos. Aitken for discharging tar in a cold state on to the road surface. The apparatus consists of a receiver, for tar and air under pressure, mounted at the rear of a supply tank, which may be an ordinary water cart. Air is forced into the receiver at a pressure of 100 to 150 lbs. per square inch by means of a pump driven off the wheels of the

vehicle through a pinion, chain and crank shaft. When the desired pressure is once attained, as it generally will be on the journey from the depot to the road, the valves are adjusted so as to pump tar, or tar and air, from the tank to the receiver; when the pressure rises to 200 lbs., or a little over, spraying may commence. The tar is liberated from the receiver through a horizontal distributing pipe, at the rear of the wagon close to the ground, and discharged under pressure through spraying nozzles., While spraying the valves are adjusted so as to admit the same quantity of tar to the receiver as is being liberated at the nozzles. The tar is discharged in the form of a fine spray, which, although cold, completely covers the road surface and eliminates all labour of brushing. The cost, in England, of applying the tar is about 2d. per gallon, or about 1/4d. per square yard, which shows a considerable saving on that of manual labour.

217. **Durability.**—Close observation shows that, under moderately heavy traffic, tarring checks the wear of the stone almost entirely for at least one year. One of the principal advantages is that the tar gives the stones themselves a tough wearing coat, resisting abrasion. In addition, it acts as a preventive of dust and mud, and at the same time saves the expense of frequent waterings in dry weather. Tar is liable to oxidation, and perishes on long exposure, weathering off a road but little used, probably almost as soon as off one of moderate traffic. It should, however, be noted that a coating of tar possesses considerable powers of recovery when apparently pretty well perished after a spell of wet weather. The occurrence of two or three sunny days after such a period causes the tar to re-cement in a rather remarkable manner, and invests it with a fresh lease of life. This does not apply to tar in the body of a road and not reached by the sun. Generally, it may be assumed that tar painting must be repeated at intervals of a year, whether the traffic is extremely light or moderately heavy, while under more severe conditions two coatings per annum will be required. Thus for tar painting to be economical the restoration of the annual wear of the untreated road should cost as much as the expense of one, or in some cases two, coats of tar. Experience goes to

show that moderately trafficked roads of the right class may be repainted indefinitely without wear or deterioration, provided that the foundation is sound enough to prevent hollows appearing in the surface as the result of subsidence. Roads tar painted annually for five or six years are to-day rather smoother and better than they were the season after receiving their first coat. As is to be expected, tar painting does not stand particularly well under extremely heavy traffic, and its use on city streets or roads subject to such is not recommended, although a coat will, in many instances, delay the necessity for remetalling for quite twelve months. We anticipate that further experience will disclose the necessity, after some years of tar painting, for the removal by loosening and sweeping of the whole of the oxidised crust of tar and sand before retarring the bared upper surfaces of the stones.

218. Cost.—Typical examples of the cost of tar painting by hand, as carried out by day labour in Brighton, Victoria, with tar at 3½d. per gallon at the gas works, about a mile distant, is given in Table XV. It will be noticed that the cost of second and subsequent applications is, for obvious reasons, less than the initial coating.

TABLE XV.

Street.	Year of Application.	Square Yards Laid.	Cost in Pence per Square Yard.		
			Tar.	Labour, Dust, and Cartage.	Total.
Male-street ..	First	2,530	.91	.42	1.33
Bay-street ..	First	10,220	1.07	.46	1.53
New-street ..	Second	7,650	.74	.48	1.22
Nepean-road ..	Second	9,800	.70	.47	1.17
Church-street ..	Third	5,750	.53	.40	.93

At present prices each square yard of consolidated metal and binding in the same town costs about 3d. per inch of thickness, so that, if each coat of tar prevented half an inch of wear, its application would be fully justified, apart from its great advantages of cleanliness and comparative noiselessness. That it does this and more has been fully proved.

CHAPTER XI.

TAR MACADAM AND ASPHALTUM ROADS.

219. Tar as a binder has come into prominence in England and elsewhere within the last few years. Although over half a century has elapsed since tar macadam was first tried, really satisfactory results were not obtained until comparatively recently, when the materials and methods became better understood. The general principles of tar macadamising are discussed in the succeeding pages, an effort being made to point out the practical advantages, disadvantages, and limitations of the system as applied to Australasian conditions.

Materials.—Limestone, on account of its absorbent nature, is considered by many to be the best rock that can be employed for the purpose. As against this view, it must be remembered, however, that porous rocks of any kind are generally far too soft for the wearing coat in road works. Basalts and other dense rocks cannot possibly absorb any tar, but those presenting a rough surface when fractured are probably preferable to any of the soft stones. Flints and other quartzose rocks that fracture with a smooth surface are of very little use for tar macadamising.

Tar-mac, consisting of iron furnace slag mixed and coated with tar when hot, and laid in a similar manner to tar macadam, is popular in England. Furnace slag is not, as yet, produced in sufficient quantities in this country to admit of its use in road construction, so it need not be further considered at present.

The quality of the tar used is most important, and needs closer investigation than does that used for tarring the surface of metalled roads (see § 214). For tar macadam, not only must the whole of the water be driven off, but practically all the volatile oils in addition. Boiling for from four to six hours is very often necessary to ensure the required consistency. Very poor tar can be improved by the addition of a small proportion of pitch. The consistency of tar should be such that, when placed between a finger and thumb, it will, when cold, draw out like cobbler's wax. Tar should invariably be drawn from the bottom of storage tanks, as water and the volatile oils rise to and float on the surface.

220. Mixing Tar Macadam.—Tar macadam is laid in the form of tarred metal previously mixed at some depot, or alternatively the tar is applied after the broken stone is laid and rolling partially completed. The first-mentioned method is recommended as the best where the use of a convenient mixing plant can be obtained, the second only in hot climates where special appliances are not available.

Tar macadam is mixed mechanically by a simple apparatus patented by the Railway and General Engineering Company, of Nottingham. A machine of similar design has recently been installed by the Melbourne City Council, and is capable of turning out 10 tons of tar macadam per hour.

The usual method adopted in the preparation of hand-mixed tar macadam is as described below, the work being carried out in a covered shed, or on the roadside if climatic conditions permit.

Wherever the mixing is carried out it is essential that the stone be thoroughly dry before the tar is applied. Care must, however, be taken that the metal is not ruined by calcination or the tar by over-heating. If there is the least dampness in the metal it must be dried on a drying floor, best made of cast-iron plates about 1 in. thick (steel is liable to warp and twist), under which a small fire is kept burning. In fair-sized plants these rest on low brick walls, arranged so as to circulate the heated gases under all the plates, and finally to pass them round coppers, containing tar to be heated, before reaching the chimney.

A layer of road metal is spread on the drying plates to a depth of 6 to 9 in., according to the moisture present, and turned over several times; the stones must not be over-heated, or the coating of adherent tar will be too thin. Warm tar is then poured over the dried metal, and the whole is turned over and well mixed until every stone is well coated. If prepared at a depot, tar macadam may, with advantage, mature for six weeks or two months, by which time the tar will have been absorbed to the utmost, and any surplus will have drained off. If mixed on the roadside on really hot sunny days, artificial drying is generally unnecessary, but the mixing should be done on plates under which a fire can be lit at any time, for it is essential that the stones be not only dry, but hot, in order to take the tar.

For every cubic yard of 2½-in. road metal measured loose 12 to 14 gallons of tar are required. For stone broken to 1½-in. to 1-in. gauge allow 16 to 18 gallons per cubic yard.

221. Laying Tar Macadam.—Two-course work is recommended in all cases where previously mixed tar macadam is to be laid. It will generally be necessary to strip a layer of the old road crust, and for this work great savings can be made by the use of a scarifier attached to, or drawn by, a steam roller or traction engine.

The lower layer should be composed of tar macadam 2½-in. gauge, well assembled, and thoroughly compressed to a thickness of about 4 in., by a steam roller for preference. The top course, consisting of tarred stones 1½ to 1-in. gauge, is spread with rakes about 3 in., so as to finish about 2 in. thick. A certain amount of the finer material will, during rolling, be forced into the interstices of the larger stones, and will make the road more homogeneous and durable.

When rolling tarred material of any sort, the roller wheels must be kept damp with water to prevent adhesion. Care should be taken to exclude stones smaller than 1-in. gauge from the wearing coat, because tarred material finished to a fine face never withstands heavy traffic. It is hopeless to expect a road to be anything but a failure if provided with a face only fit for footpaths. This rule is, nevertheless, very frequently violated.

Even spreading is most essential to success, and care should be taken to select experienced men for this duty. Stone dust or sand is usually sprinkled on the surface, after which the rolling is continued until the whole is solid. Tar macadamising in best undertaken in the summer months, and then only on warm days.

222. Tarring after Spreading.—By the alternative method ordinary road metal is spread in the usual way to a depth of 4 to 6 in., and well, though not finally, consolidated by rolling. Coarse stone screenings are then spread on the surface and forced into the interstices with a heavy roller, after which the whole is sprinkled with hot tar generally poured from cans. The surface is covered with fine screenings, and after an interval of several hours, during which the stone is supposed to take up the tar, thorough rolling is undertaken and completed as rapidly as possible.

When carried out in very warm weather, the system works well, but even then the hot tar is to some extent chilled on contact with the cooler stones, and there is difficulty in thoroughly coating all the surfaces. For this system a saving of tar is claimed, but this can only be at the expense of efficiency. There is, moreover, a danger of losing that which penetrates to the road bed, only to exude in the form of springs at some lower part of the road.

The introduction of tar-spraying machines, such as described in § 216, will doubtless provide a satisfactory and ready means for applying tar to macadam without the disadvantages mentioned.

An article in the "Engineering Magazine," of London, states that a novel way of macadamising has been adopted by Mr. A. Gladwell, an English engineer. His method is as follows:—

A matrix of tar and fine granite chips is laid on the old surface of the worn road to a depth of ½ to ¾ in. Upon this the road metal is spread to a depth not exceeding 4 in. and rolled immediately with a steam roller. The rolling forces the stone down into the matrix, the result being that if proper proportions of stone and matrix have been used almost the whole of the interstices in the former will be filled. A small quantity of the matrix is then spread upon the surface, brushed in, and a final rolling given. It is stated that the cost of this system need not be more than 2½d. per square yard above the cost of an ordinary macadamised granite road of the same thickness, and that the result as to smoothness of surface, watertightness, and lasting qualities is much superior.

The method seems to be open to the following objections:—

(1) The old surface of the road not being broken up, the bond between the new and the old work is not likely to be good.

(2) As the surface of the old road is almost certain to be uneven, it would be necessary to spread unequal thicknesses of stone and matrix, the almost certain result being a cuppy new road. We fear that unless the old surface of the worn road was much smoother than could be reasonably expected, the result would not be quite satisfactory.

223. **Cost of Tar Macadam.**—To the price of the metal delivered, the cost of the tar and mixing, as well as that of spreading and rolling, must be added. If the mixing be done at a depot the cost of extra loading and haulage must not be forgotten. The cost per cubic yard of consolidated material, laid on an old road as a foundation, is, for typical cases, about as under:—

Bottom Course—	s.	d.
1.3 cubic yards of metal 2½-in. gauge, measured loose, delivered at depot, at 6s. 6d.	8	6
14 gallons of tar, at 3½d.	4	1
Heating of tar and mixing	1	9
Loading and carting one mile to works	1	2
Spreading and assembling with rakes	1	0
Rolling	0	6
Total	17	0

Surface Coat—	s.	d.
1.2 cubic yards of metal, 1½-in. to 1-in. gauge, measured loose, delivered at depot, at 6s. 6d. per cubic yard	7	11
18 gallons of tar, at 3½d.	5	3
Heating of tar and mixing	2	0
Loading and carting one mile	1	2
Spreading, assembling, and dusting	1	6
Rolling finally	0	6
Total	18	4

For bottom course, 4 in., and surface coat, 3 in., equal to 2 in. when consolidated, the cost per square yard, exclusive of excavation and preparation of foundation, is about as under:—

	s.	d.
1/9 cubic yard of consolidated material, at 17s., say ...	1	11
1/12 ,, ,, ,, 18s. 4d., say	1	6
Total	3	5

224. Maintenance of Tar Macadam.—The life of tar macadam roads is not definitely known, but depends on the traffic, and, of course, upon the materials and methods employed in construction and maintenance. Roads subjected to moderately heavy traffic should, with a yearly dressing of tar or mineral oil, require but little further attention for, say, four years. Repairs thereafter are effected by resurfacing with tar macadam at a cost of about 1s. per square yard at intervals of about two years.

225. Advantages of Tar Macadam.—Well-maintained tar macadam possesses a smooth, clean surface that is moderately free from dust and mud, and is more durable than ordinary macadam. It is impervious to water, is easily cleansed, and is comparatively noiseless. One of its chief recommendations is the fact that it sets quickly, and does not necessitate the closing of the roadway for any length of time.

226. Disadvantages of Tar Macadam.—The percentage of voids in tar macadam is high, and, in consequence, the liability to further compression is always present, notwithstanding persistent rolling during construction. Tar macadam is not well suited to newly-constructed roads owing to its liability to fracture in the event of subsidence; its use should be confined to resurfacing existing roads that have been well consolidated by use.

Tar embedded in a road does not recement if fractured, and for this reason roads of this type are not so suited for heavy traffic as roads bound in the usual manner. As a matter of fact tar macadam construction is only suitable for moderately trafficked roadways. Then, again, the embedded tar oxidises in time, and perishes, with the result that tar macadam roads inevitably break up sooner or later. Other defects are uneven wearing, and the slippery nature of the surface, which precludes its use on grades steeper than about 1 in 25.

The chief objection to tar macadam lies in its high initial cost, especially where coal tar cannot be obtained at low rates; then, again, the cost of maintenance is high. While admitting that tar macadam makes a very nice road under favourable conditions, we are of opinion that it is too costly for general application. The fact that macadam continues to compress for years after construction, combined with the knowledge that tar perishes, points to the desirability of introducing the more ordinary binders possessing marked cohesive properties. We are strongly of opinion that in most cases it is more economical to tar the surfaces of well-consolidated macadam roads, in which the best wearing materials have been used, than to coat each stone separately. If a street so constructed, and tarred twice a year, will not withstand the traffic to which it is subjected, it is time to pave that road with some more lasting material, such as wood blocking or asphaltum. On the subject of tarring metalled roads see §§ 213 to 218.

227. **Bitulithic Pavement.**—Tar macadam is not greatly favoured by American engineers, who, realising the perishable nature of tar in a position where it cannot be renewed without breaking up the whole road, are averse to its use. In the year 1901 a new form of patented pavement, called bitulithic, was introduced by the Warren Bros. Co., and rapidly sprang into favour, since well maintained.

The foundation consists of either a layer of broken stone 6 in. thick after compression, or, preferably, a layer of Portland cement concrete finished parallel with and 2 in. below the surface proposed for the finished pavement. This is coated with a semi-liquid bituminous composition sufficiently flexible to unite freely with the cold stone. On top of this is spread a coating of hard bituminous cement at the rate of one gallon per square yd., thoroughly binding the foundation base, and making it ready to unite with the bituminous concrete wearing coat. This wearing coat is composed of tough broken stone, 1¾-in. to 1-10-in. gauge, mixed in rotary drums at a temperature of 250 F. with enough bituminous cement (about 10 to 12 per cent. of the whole volume) to coat the particles of stone and fill all voids. This is spread, and rolled to finish 2 in. thick. After rolling, a coating of quick-drying bituminous composition is applied for the purpose of filling any depressions. On this is spread a quarter-inch layer of stone chips, which are rolled in to form a gritty surface, to afford good foothold. The bituminous cement consists of bitumen distilled from coal, and passed in a gaseous state through and purified by water, matter soluble in water being thus removed. The pavement formed is said to be less noisy, dusty, and slippery than asphalt, possessing all its advantages, with but few of its defects.

The cost in America, including foundation base of broken stone 6 in. thick, ranges between 7s. 6d. and 10s. per square yd. The cost, being considerably less than that of wood blocking or sheet asphaltum, is distinctly in its favour; no pavement of this class has, however, been laid in Australia up to the present, though the establishment of works for the manufacture of bitulithic has been proposed.

228. Asphalt Macadam.—A form of macadam road, in which liquid asphalt is used in place of tar as the binder, has been successfully adopted in Redlands, California, where, owing to the excessively dry climate, ordinary macadam ravels so rapidly that its general use is not practicable.

The foundation course is composed of broken stone, 1½ to 3-in. gauge, and the wearing coat of similar material ¾ to 1½-in. gauge. The interstices are filled as far as possible with stone screenings, and each course is thoroughly rolled, plenty of water being used in the operation. When the moisture has dried out, liquid asphalt previously heated by a steam coil is evenly distributed from a tank on a wagon to the extent of about 2 gallons per square yd. until the voids are filled. The liquid must contain not less than 75 per cent. of bitumen, and the specific gravity must not be less than 10 deg. nor more than 12 deg. Beaumé. After sprinkling, the surface is dusted with stone grit until the liquid ceases to appear. Owing to the much greater durability of asphalt as compared with tar, the method is a vast improvement on tar macadamising. A point in its favour is the facility with which repairs can be made. There is a limited amount of crude oil available, but caution is necessary in purchase, as spurious material is on the market. In California the total cost is about 2s. 3d. per square yd., with oil at 1¼d. per gallon. In this country the cost of the oil is much greater, though that of labour and stone is about the same.

229. Asphaltum Roads.—The term "asphalt" is erroneously applied to indicate pitch prepared from coal or Stockholm tar, and to tar pavements in general. Artificial pitches produced from coal tar, residuum oils of petroleum, naphtha, Stockholm tar, &c., are similar in composition, but quite inferior to the natural product. Asphaltum pavements are of three classes, all of which are in use in Australasia to a limited extent.

(a) Natural rock compressed asphalt.
(b) Mastic asphalt.
(c) Trinidad asphalt compressed while hot.

The materials and methods used in each of these are described below.

230. Natural Rock Asphalt.—This consists of calcareous or siliceous rock impregnated naturally by bitumen or pitch. It is found in most countries, and mined or quarried like coal. No deposits of any value have, however, been discovered in Australasia as yet. Asphalts with a limestone base are produced principally at Val de Travers, Canton of Neuchatel, Switzerland, Seyssel in France, Sicily, and Limmer in Germany.

California, Kentucky, Cuba, &c., furnish natural sandstone asphalt rock in limited quantities. This class of material is said to afford considerably better foothold when laid as a pavement than do any of the rocks with a limestone base.

Val de Travers asphalt, typical of this class of rock, contains about 89 per cent. carbonate of lime and 11 per cent. of mineral bitumen. When viewed under the microscope most of the particles are found to be coated with asphaltum. The rock is quarried, crushed to fine gauge, and powdered in a disintegrator. The powder is screened, and all coarse grains rejected for further pulverising.

Before use the powder is heated for about four hours in slowly revolving cylinders to a temperature of from 250 deg. to 280 deg. F., various samples of rock, obtained possibly from widely separated mines, being blended till the required percentage of bitumen is obtained in the mixture. Heating is necessary both to drive off moisture and to render the material sufficiently plastic to bind well. The hot powder retains its heat for some hours, and is conveyed to the work in closed receptacles made for the purpose, or in carts covered with asbestos sacking.

The foundation of an asphaltum roadway must invariably be of cement concrete at least 6 in. thick. Before any asphalt is laid the concrete base must be absolutely dry, or honeycombing and other troubles will ensue. In city streets the heated asphaltum is laid about 3 in. thick measured loose, so as to finish 2 in. when fully compressed; for city streets of very light traffic 1½ in. is sufficient. Each ton of material covers approximately 11 square yds. 2 in. thick. Fig. 81 shows the arrangement adopted. The surface is rammed with hot tampers, and is afterwards thoroughly compressed with hot irons. The compression is frequently completed with a steam roller or one of the motor rollers described in Chapter VII. The amount of crown and desirable profile for asphaltum pavements are discussed in § 243.

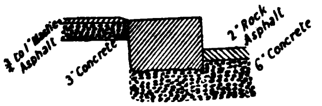


Fig. 81.

Rock Asphaltum Carriageway and Mastic Footpath.

Mastic (Artificial) Asphalt.—The use of mastic asphalt is practically confined to footpaths and yards. It is not recommended for carriageways. It consists of natural rock asphalt, such as described above, with refined natural bitumen, such as comes from Trinidad, added to bring the total proportion in the mastic up to about 15 per cent. The mixed product is run into moulds to cool, and is shipped in the form of blocks or cakes weighing about ½ cwt. Before use the blocks are broken up and heated; 20 to 40 per cent. of limestone grit under ½-in. gauge, or specially clean sand, is then added, together with a flux of a further 5 to 7 per cent. of bitumen, the precise quantity depending on the maximum sun temperature experienced in the locality.

230a. Trinidad Asphalt.—This is a mixture of prepared bitumen sand, finely crushed stone in the form of clean grit, and stone dust. The bitumen used in Australasia is imported principally from the British West India Island of Trinidad. Trinidad pitch is a crude asphalt containing much siliceous, some vegetable matter, and water to the extent of one-third to a quarter of its weight. The pitch is mined by pick and shovel, and mostly shipped in its crude state. In manufacture the water is driven off by heat; the mineral matter remains, but is no detriment. The refined pitch contains about 55 per cent. of bitumen, but is too hard and brittle for paving purposes. It is softened for use by the addition, when heated to about 325 degs. Fahr., of a flux, in proportions from 13 to 20 per cent. by weight, of heavy residuum oil or pure refined bitumen, which must not contain oils volatile at ordinary temperatures that will leave it brittle in time. The mixture is thoroughly stirred, and when cool constitutes the bitumen referred to below. Bermudez (Venezuela) pitch, which, however, is rarely imported to this country, is similar to Trinidad, but purer, and contains as little as 3 per cent. of water. It is more easily dried, and requires less flux. The bulk of the supplies to Australia are, however, drawn from Trinidad.

Binder or Cushion Coat.—This is placed, as shown in Fig. 82, directly on the concrete foundation in a layer 1 in. thick when rolled, composed of screened broken stone, slag, or gravel, not larger than 1-in. ring gauge, mixed with plastic bitumen in the proportions of about 15 gallons to 1 cubic yd. of metal. The stones should be coated, as in tar paving, but there should be no excess to fill the interstices. The mixing must be done in revolving heaters. The spreading is effected with hot rakes, and after immediate ramming this cushion coat is thoroughly compressed with hot

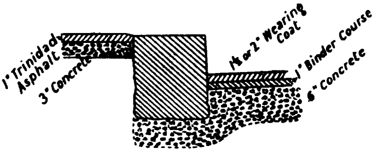


Fig. 82.

Trinidad Asphaltum Carriageway and Footpath.

irons, and when possible finished with a heavy power-driven roller. The modern tendency is to omit the cushion coat, and to lay the whole in one thickness.

Wearing Coat.—The wearing coat should be applied the same day as the binder if possible. It is composed of approximately 10 per cent. bitumen, as described above, about 80 per cent. of sand in varying sizes of grain, so as to reduce the voids, and about 10 per cent. of powdered limestone to further increase the density. The greatest skill is required in the determination of the proportions of the constituents. The mixing is done at a temperature of about 280 deg. Fahr., and the stuff is transported in closed receptacles or covered carts. The spreading is done with hot rakes to a thickness of about 3 in. to compress to 2 in., or 2½ in. if a 1½-in. coat is sufficient. The first compression is by a hand roller, weighing about half a ton, or by rammers. The surface is then dusted or sprinkled with hydraulic cement, which gives it a soft, grey colour. Further rolling with a steam or motor roller is recommended. The street can then be thrown open to moderately heavy traffic at once.

231. **Asphalt Composition Blocks.**—Blocks composed of bitumen, finely-crushed stone, and limestone dust, have been laid in various places in Australia, notably Sydney. As a street pavement they have been little used in this country, though many miles have been laid abroad. Of recent years improvements have been introduced, and whereas the depth of the blocks was formerly 4 in., it has been reduced to 3 in., and even 2 in., with face measurements 12 in. by 4 in. The blocks contain about 10 to 13 per cent. of bitumen, and are moulded under a pressure of 2 to 2½ tons per square in., and cooled in water. The pavement is laid with close joints on a concrete base, just in the same way as wood blocking. Compression being completed at the factory, subsequent treatment with hot irons and rolling are unnecessary. Blocking is less slippery than sheet asphaltum, and can be used on somewhat steeper gradients. Manufacturers are giving attention to the improvement of asphaltum composition blocks, the cost is being cheapened, and developments in the near future may be expected.

232. Cost, Wear, Life, &c., of Asphaltum Roads.—The reduction in thickness is due more to compression than to wear, which is very slight indeed. Lack of traffic is more detrimental than excess, provided, of course, that the constituents are proportioned so as to prevent the material from becoming so soft in summer as to bring about "waving." Extreme cold is severe on asphaltum, and contraction is liable to cause cracks. Oil and leakage from gas mains soon rot asphaltum roads. Asphalt pavements are extremely smooth, and those in which bituminous limestone is used afford but little foothold on grades steeper than 1 in 50, though 1 in 40 is occasionally laid. Trinidad asphalt is not so slippery, though caution is required after 1 in 33 is passed. The limit may be set down at about 1 in 25. Leading asphaltum companies are prepared to maintain pavements laid down by themselves for periods up to twenty years, and to hand over a good serviceable pavement on the expiry of that term. Pavements have occasionally been known to last close on twenty years without repair of any sort. Such cases are rare, and more frequently the whole surface will have been repaired within that time until the pavement has been practically renewed. The cost of repair and maintenance depends very largely on the traffic, the foundation, the climatic conditions, &c. In Australasia, companies are prepared to lay down asphaltum roadways at a cost, inclusive of concrete foundation 6 in. thick, of about 20s. per square yd., and to subsequently maintain them for a period of twenty years or so at a charge, varying with the conditions, but amounting to about 6d. to 9d. per square yd. per annum. In Queen-street, Auckland, where the traffic is confined and unusually heavy, the pavement laid by the Neuchatel Asphalt Company was maintained for five years free of charge, and is to be kept in order for a further term of twenty years at 9d. per square yd. per annum. This pavement at the beginning of 1908 was in excellent condition, and showed but little sign of wear. This street is for a great part of its length on filled ground, and when the double electric tram line had been for some time in use, it was found necessary to reconstruct practically the whole of the track there by driving 8-in. x 8-in. ironbark piles, spaced 7 ft. 6 in. centres, under each line of rail, and placing on the top of each a totara corbel 8 in. x 8 in.; on these, again, rested 10-in. x 8-in. longitudinal ironbark stringers, the whole forming continuous timber supports for the rails. The road crust was then formed as follows:—

"The space between the stringers was filled in with rubble, consisting of old concrete, bluestone, scoria, &c. This was rolled with a small steam roller, and the whole width of the two tracks, 18 ft. 6 in., covered with 7 in. of concrete to the under side of the rails, and the space in between the rails filled up to within 2 in. of their top surfaces, the rails thus resting on and being embedded in a solid bed of concrete of a total depth of 11½ in. from the under side of asphalt, and 7 in. below the bottom of rails. Strips of mastic asphalt were then laid along the rails, and afterwards the paving was finished with ordinary Neuchatel powdered asphalt. After a year's use this road appeared to be in perfect order notwithstanding the heavy traffic."*

233. **Materials and Methods Compared.**—Trinidad asphalt pavements originated in America in 1871, and their use has spread to Europe. Nowadays practically none other than Trinidad asphalt is to be found in America. The principal reason for this is the absence of large supplies of natural bituminous rock on that continent and the comparative ease with which Trinidad bitumen can be obtained. Trinidad is not so hard as natural rock asphalt, but, on the other hand, it is less affected by heat, is less slippery, and is slightly cheaper. Trinidad asphalt requires a great deal of attention in refining and mixing, and, as mentioned above, its preparation must be left to experts. Care should be taken to entrust work to reliable manufacturers only if the genuine article is to be secured. Imitations containing tar to the extent of 25 per cent. are said to be passed off by unscrupulous firms; in fact, the tarry odour sometimes discloses its presence.

Composition blocks can be laid without skilled labour, in cold weather if necessary. Their chief merit lies in the simplicity with which they can be set in position and the slightly extra foothold afforded.

---

* Information supplied by the City Engineer of Auckland.

For street pavements the practice is to contract with reliable companies and firms for not only the laying-down, but the maintenance for a period of years at a fixed price per square yd. per annum. Five-year maintenance periods were formerly adopted; modern practice raises this to twenty years, as some faulty pavements will not commence to break up within the first five, or even ten, years.

Both Trinidad and natural rock pavements are laid in Australasian cities and the larger towns with satisfactory results. Their more extended use is only a matter of time.

CHAPTER XII.

PAVED ROADS.

234. Road pavements apart from macadam are, for the present, limited in Australasia to wood blocking and stone sets. Concrete, asphaltum, and bricks are used to a very limited extent. Provided that the materials are good, and the foundations sound, Table XVI. indicates the relative orders of suitability of wood paving, asphaltum, stone sets, and macadam from various points of view under Australasian conditions.

TABLE XVI.

QUALITY.	RELATIVE ORDER OF SUITABILITY.			
	First.	Second.	Third.	Fourth.
Life as a smooth pavement	Asphaltum	Wood blocking	Stone paving	Macadam
Life before wearing through	Wood blocking	Stone paving	Asphaltum	,,
Foothold	Macadam	,,	Wood blocking	Asphaltum
Ease of traction	Asphaltum	Wood blocking	Macadam	Stone paving
Economy in first cost ...	Macadam	Stone paving	Wood blocking	Asphaltum
Low cost of maintenance under heavy traffic	Stone paving	Wood blocking	Asphaltum	Macadam
Noiselessness	Macadam	,,	,,	Stone paving
Ease of cleansing .	Asphaltum	,,	Stone paving	Macadam
Freedom from dust and mud	,,	,,	,,	,,
Sanitary qualifications ..	,,	,,	,,	,,
For very heavy city traffic ...	,,	,,	,,	,,
For heavy intermittent traffic	Wood blocking	Asphaltum	,,	,,
For light continuous traffic...	,,	,,	Macadam	Stone paving.
For light intermittent traffic	Macadam	Wood blocking	Asphaltum	,,

An unyielding foundation is a first requisite in any pavement, but a slight resilience in the wearing coat is highly desirable as tending to reduce slipperiness and unevenness in wear of the surface. In the selection of pavement materials the whole range of qualities must be fully considered, the advantages being set off against the disadvantages.

235. **Durability.**—When considering the durability of a pavement its ultimate life before being worn completely through is of small importance compared with its efficient life as a smooth and satisfactory pavement before renewal is necessary.

The life of any pavement depends so much upon local conditions that the statistics on the subject are practically valueless unless the circumstances are set forth. When comparing the economy of pavements to be subjected to heavy city traffic, on the lines indicated in § 18, Chapter II., the efficient life of various pavements may, subject to modifications to suit local conditions, be taken as under:—

Wood pavements of Australian red-gum, jarrah, and similar timbers, if coated with tar and sand, at least	25 years.
Asphaltum	18 „
Bluestone sets	18 „
Granite sets	22 „
Brick of special quality	12 „

Suggestions concerning the desirability of establishing the relation between traffic and wear of various road surfaces have been discussed in § 193.

236. Foothold.—As a rule the smoother the surface the less secure the foothold afforded to horses. On the other hand, smooth surfaces reduce tractive resistances, and, to some extent, therefore, the necessity for such efficient foothold.

The maximum gradients for which the several kinds of pavement are suited are about as under:—

Wood blocking	1 in 25
Stone sets	1 in 12
Rock asphalt	1 in 50
Trinidad asphalt	1 in 25
Concrete	1 in 20
Brick	1 in 40

237. Cross Gradients.—Crowns and profiles or forms of cross section suitable for paved roads can be ascertained from the formula and table given in § 243. As there explained, the convexity of paved roads need not increase with the longitudinal gradient as it should for macadamised roads.

238. Wood Paving.—Although wood, in the form of blocking, was employed as a paving material in America in 1835, and in London in 1839, it was not until 1869 that any considerable length of this class of road was laid down. During the latter year 5½ miles of wood pavement were constructed in Brooklyn, U.S.A., under patented methods, and its use on an extensive scale may be said to date from about that time.

Despite the successful results from many of the early trials, wood as a pavement encountered severe criticism, and its introduction for the purpose was met with virulent opposition. Much of the prejudice was due to adverse reports from America, where sufficient care had not been exercised either in the choice of materials or in the mode of construction. As an example of premature condemnation we find the following in reference to the Brooklyn pavements of 1869:—

"The patent pavements, so called, may be considered as having had their day for streets of heavy traffic. For streets of small and light travel, there are some forms which might be used to advantage possibly, but on such streets an improved form of cobble stone pavement will be found to serve every purpose of an economical and durable and sufficiently smooth pavement for light travel."

The pavements referred to were laid only five years before, yet we find a cobble pavement preferred to wood blocking as then developed. The conclusion is not so surprising, however, when we learn that the pavements in question were of untreated softwood blocks, merely laid on plank foundations placed on the ground, and with joints about an inch wide. In 1878 the Society of Arts, England, reported adversely to softwood pavements for London on sanitary grounds.

239. August, 1880, saw the inception of wood pavement in Australia, when an experimental strip consisting of eight varieties of woods was opened for traffic in King-street, Sydney, N.S.W. The test included four hardwoods and four softwoods, and the results proved conclusively the superiority of the former.

In October, 1893, the City Surveyor, Mr. R. W. Richards, reported that all the experimental blocking, including those of 1880, had been removed, and the paving relaid with blackbutt and tallow-wood, the different timbers having worn as follows:—

Blue gum	$\frac{1}{10}$ of an inch per annum.	
Mahogany	$\frac{1}{8}$,, ,, ,,	
Turpentine	$\frac{1}{17}$,, ,, ,,	
Brush box	$\frac{1}{7}$,, ,, ,,	
Spotted gum	$\frac{1}{7}$,, ,, ,,	
Baltic deal	$\frac{1}{10}$,, ,, ,,	
Colonial cedar	$\frac{1}{12}$,, ,, ,,	
Blackbutt	$\frac{1}{26}$,, ,, ,,	
Colonial pine	$\frac{1}{22}$,, ,, ,,	
Blue gum	$\frac{1}{12}$,, ,, ,,	(about)
Red gum	$\frac{1}{10}$,, ,, ,,	

It must be noted that the above were all laid with very open joints, and that although the figures give comparative results, the wear would have been less with the close jointing since adopted. The paving of the intersection of Collins and Swanston Streets, Melbourne, was carried out later in the same year. The early experiments proved, on the whole, successful, but in 1884 a board appointed by the New South Wales Government reported adversely on wood pavements, condemning them from every point of view. Notwithstanding much unmerited condemnation, wood blocking has steadily grown into favour until now it may be said to occupy the premier position among pavements in Australasia. As regards smoothness and durability it is certainly superior to stone or brick paving, and is surpassed only by sheet asphaltum and bitulithic, the high cost of which is a bar to its general adoption.

240. Timber Used.—In England and in America softwood blocks have been most favoured up till recently on account of their cheapness as compared with hardwoods. In London Australian woods have come rapidly to the front, and miles of streets are being laid down in jarrah, karri, and blackbutt, while red gum was used to a limited extent. Quite recently softwoods for pavements were once again received into favour, the prejudice in some quarters against hardwood being accounted for by its somewhat higher price, slipperiness, and alleged uneven quality. In America black gum, a species of hardwood admittedly inferior to those of Australia, is replacing the now somewhat scarce long leaf yellow pine of Georgia.

Where softwood blocks have been used they have almost invariably been treated with some preservative, such as creosote or chloride of zinc, before being laid. On the other hand, suitable Australian hardwoods do not require treatment of any kind beyond tarring when thoroughly seasoned, and may be regarded as the very best for pavement purposes.

The principal timbers now used in Australasia for wood paving are as under:—

Tallow-wood (*E. microcorys*) of coast districts of New South Wales north of Newcastle, and Queensland. Canary colour, or sometimes reddish when sawn; dries a pale brown; shrinks very little; greasy feel. Is largely used.

Blackbutt (*E. pilularis*) of north coast of New South Wales and Queensland. Pale coloured, fissile, diagnosed by narrow concentric gum veins; takes tar well. Very extensively used.

Red gum (*E. rostrata*) of Victoria, New South Wales, and South Australia. Red colour, very hard and heavy; best from open country; supply not large, being rapidly cut out.

Jarrah (*E. marginata*) of West Australia, colour from bright to dull red; not unlike red gum, and difficult to distinguish from karri; supply plentiful; largely used. Gives black ash when burnt.

Karri (*E. diversicolor*), very similar in appearance to Jarrah but somewhat lighter in colour, and burnt as a splinter it gives a white, instead of a black, ash. Supply plentiful.

Sydney blue gum (*E. saligna*) of north coast, New South Wales. Pale red colour, straight grain; supply fairly plentiful.

Grey box (*E. hemiphloia*) of the drier portions of all the States. A pale brown colour, very tough, and somewhat cross-grained; supply not plentiful, and consequently not much used for wood paving.

Red mahogany (*E. resinifera*) of north coast, New South Wales. Rich red colour; very durable, and becomes harder than ironbark; supply fairly plentiful.

Kauri (*Damarra Australis*), a soft wood of light colour, grown in New Zealand; forms an excellent pavement, but is not so durable as the hardwoods mentioned above, and is more costly.

Tasmanian blue gum and stringy bark, excellent woods for general building purposes, have been tried, and found to twist and warp rather badly. Red gum blocks cannot be excelled, but are very little used on account of the scarcity of suitable trees.

241. **Blocks.**—Wood blocks should invariably be sawn from planks of uniform dimensions, cut so that when laid the fibres of the wood shall be vertical. Round blocks, used so extensively in America, meet with no favour in Australia, and deservedly so. Rectangular ones should be used exclusively; 9 in. x 3 in. x 6 in. deep were until recently common dimensions, designed to allow of the blocks being cut down and reused when much worn. The modern tendency is to lay nothing deeper than 5 in., it having been found that the larger blocks cost about 2s. 6d. per square yd. more, without corresponding advantages; 3-in. blocks are being successfully used abroad on less important streets, but it is to be doubted whether anything less than 4 in. is advisable in any situation. In any case the length should not be equal to the depth, or occasional blocks will, through carelessness, be laid side instead of end up. If blocks so laid are missed on inspection, the fibres will soon tear off, and leave a hollow in the pavement. Wood blocks must in all cases be well seasoned, and should, where practicable, be dipped in tar some time before use, then laid dry. Frequently, however, it will be found that dipping just before laying is, on the whole, the best course.

242. **Foundation.**—Although wood blocking has a very long life if the individual blocks are kept on a perfect grade, no pavement is more easily destroyed should the surface become uneven. Stability of foundation is all-important, and experience has proved that nothing short of a bed of cement concrete will suffice; this should be 6 in. in ordinary city streets, with a maximum of 9 in. where the sub-grade is unstable. Over recently-filled trenches the concrete foundation should be strengthened as a beam by reinforcing with ⅜-in. steel rods placed within 1 in. of the bottom, say, 4 in. apart, and with the ends turned up. The foundation must

be laid to accurate gradient and side slope, and rendered with cement mortar floated in. For details see specifications § 248. It has also been found that a layer of sand between the concrete and the blocks is unnecessary. Wood is in itself sufficiently elastic, and requires no sand cushion as does stone or brick.

243. Cross Section.—The amount of crown desirable in paved streets can be computed by the following formula, devised by Mr. Rosewater in 1902 in substitution for an earlier one by himself:—

$$\begin{array}{c}\text{Crown in inches for wood block,}\\ \text{stone or brick paving}\end{array} = \frac{\mathbf{W}\,(100 - 4\,\mathbf{f})}{6000}$$

where $\mathbf{W}$ = distance between kerb in inches.
$\mathbf{f}$ = grade of street in inches per 100.

Table XVII. has been computed from this formula, which has met with acceptance by the profession. It will be noticed that in the design of paved streets generally, the greater the longitudinal slope the less the transverse slope need be; the reverse is the rule with ordinary macadamised roads, which tend to gutter out if water is allowed to flow along them.

TABLE XVII.

STANDARD CROWNS FOR WOOD BLOCK, STONE, OR BRICK PAVING.

Distance between Kerbs, in Feet.	Crown in Inches—Gradient.							
	Level.	1 in 50.	1 in 40.	1 in 30.	1 in 25.	1 in 20.	1 in 18.	1 in 15.
20	4.0	3.7	3.6	3.5	3.4	3.2	3.1	2.9
25	5.0	4.6	4.5	4.3	4.2	4.0	3.9	3.7
30	6.0	5.5	5.4	5.2	5.0	4.8	4.7	4.4
35	7.0	6.4	6.3	6.1	5.9	5.6	5.4	5.1
40	8.0	7.4	7.2	6.9	6.7	6.4	6.2	5.9
45	9.0	8.3	8.1	7.8	7.6	7.2	7.0	6.6
50	10.0	9.2	9.0	8.7	8.4	8.0	7.8	7.3
55	11.0	10.1	9.9	9.5	9.2	8.8	8.5	8.1
60	12.0	11.0	10.8	10.4	10.1	9.6	9.3	8.8
65	13.0	12.0	11.7	11.3	10.9	10.4	10.1	9.5

The profile for paved roads is usually a circular or parabolic arc in preference to a straight line cross section.

A suitable profile can be set out with the aid of Fig. 83. The half width is divided into twelve equal parts. The crown, as determined by Table XVII., is taken as unity, and the successive ordinates are calculated by applying the percentages given in the figure. For example, if the crown is 10 in. the respective ordinates in decimals of a foot will be .11, .21, .31, .40, .48, .56, .62, .68, .73, .77, .81, and .84 at the centre. Whatever the crown may be made the percentages will still apply. Fig. 84 shows a typical cross section of a wood-paved city street 99 ft. wide.

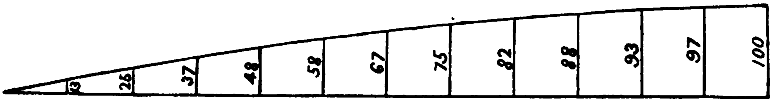


Fig. 83.

Suitable Profile for Pavement.

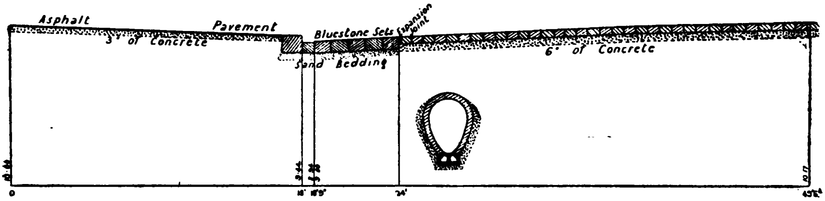


Fig. 84.

Half Cross Section of a Wood-paved Street 99 ft. wide.

244. Method of Laying.—In the early days of wood paving the blocks were set with joints 1 in. in width between the rows, the object being to afford foothold for horses. It was found, however, that the arrises of the blocks were rounded and damaged, and that the road soon became almost as rough as one made with cobble stones. The joints were reduced in width from time to time, until now the blocks are laid as close as they can be packed. After the pavement has been in position a few months some shrinkage is noticeable. It should then be dressed with lightly-distilled or well-boiled tar mixed with sand. See § 214, Chapter X. The effect is to fill the joints and to form a water-tight skin, which reduces the slipperiness quite appreciably, and renders the road less noisy. By the exclusion of water from the joints premature decay is prevented, and the absorption of organic matter likely to give offence is reduced to a minimum. Although swelling of wood pavements is greatly minimised by waterproofing the surface with a top dressing of tar, contraction and expansion cannot be entirely eliminated. To meet the difficulty it is necessary to provide expansion joints, not only along the edge of the pavement, and between it and the street channel or kerb, but transversely for the full width of the pavement, at intervals of about 30 ft. These joints may be filled with mastic, clay, or even sand. A suitable grout for the purpose is composed of a hot mixture of about 100 lbs. of pitch to 1¾ lbs. of creosote oil. In Sydney the difficulty is minimised by laying at intervals blocks with the abutting faces inclined at an angle of 45 deg. Considerable trouble was formerly experienced in Melbourne by the closing of the cable tramway slot as a result of expansion of the blocks; the introduction of the mastic joint, however, removed the difficulty almost entirely. On gradients steeper than 1 in 25 it is advisable to set the blocks with ¼-in. joints to give better foothold to horses and to grout with pitch.

245. **Slipperiness.**—When the gradient is about 1 in 25, wood blocking affords barely sufficient foothold for horses; for steeper inclines the choice of pavements is practically confined to stone sets, or macadam in some form. Formerly, it was necessary to sprinkle wood-blocked streets with large quantities of sand after every shower of rain. Top dressing with tar, liberally sanded when laid, has to a large extent cured the trouble; nowadays the application of a very little sand or fine gravel is all that is required under the worst conditions.

246. **Durability.**—Well-laid wood blocking of the best timber is more durable than stone pavement of almost any description. Basalt sets in Flinders-street, Melbourne, subjected to extremely heavy traffic, wore at the rate of ⅜ in. per annum, whereas red gum blocks in position very nearly as long were only worn down at an average rate of 1-6 in.

each year, notwithstanding the open joints with which they were laid. Wood pavements in Queen-street, one of the busiest thoroughfares in Sydney, are said to have worn as little as 1-16 in. in eight years. The life of softwood pavements, as laid in some American towns, is only six years. In Australia untreated wood block pavements have been assigned a minimum life of twelve to sixteen years, which is less than that of asphaltum. Since top dressing with tar and sand has become the vogue it is difficult to say to what extent the life of the pavement has been prolonged. The probabilities are that modern pavements may be expected to last for from twenty to twenty-five years without renewal, if so treated, at a cost of from 2d. to 3d. per square yd. per annum.

The concrete foundation, it must be remembered, will last indefinitely if well laid in the first instance. The wood-paved roads of Australasia are, taken as a whole, admittedly equal to any that can be found in the world.

Before undertaking the wood paving of any street the engineer should consider well what sewerage or other connections will be required in the near future under the proposed pavement, and these should be provided before it is laid. It is extremely bad business to have to root up a good pavement at a cost of several pounds to lay down a connection which might have been made if due prevision had been exercised when the work was going on, possibly at the cost of as many shillings.

247. Cost of Wood Blocking.—In the early days the cost per square yard in Sydney for a complete pavement, including concrete foundations, was over 26s. By 1886, when blocks cost £10 10s. per thousand, this was reduced to 21s., and in 1905 the cost fell as low as 13s. 5d. in a contract comprising 13,000 square yds. of pavement. Renewal of wood blocking on existing concrete foundation costs 9s. to 10s. per square yd., with 5-in. blocks at £7 per thousand. The cost of new pavements, with 5-in. blocks laid complete on 6 in. of concrete, runs from 15s. to 18s. per square yd., depending on the size of the job.

248. Example of Specification for Wood Blocking in a City Street:—

SPECIFICATION referred to in foregoing Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement [for examples of these see Chap. XVII.], and to be observed in the woodblocking of certain streets in the City of......................., as shown by locality plan in red colour.

General Description.—The works of this contract consist of the breaking up and removal of the existing road crusts of the streets to be paved, the excavation and consolidation of the sub-surface to even formation, the laying of a layer of concrete of the thickness shown by cross sections or ordered, and the setting thereon of the wood blocks. All the work is to be done having due regard to prevention of injury to property, and to avoidance as far as may be of interruption to traffic, as provided for in the clauses below.

Nature of Contract.—It is to be clearly understood that this is to be a Schedule of Rates Contract, and not for a lump or bulk sum. The quantities given in the schedule are approximately correct, but the Engineer shall have the right to order such extras, additions, deductions, enlargements, deviations, alterations and omissions as he may decide on, and the Contractor will be paid only for the actual measured quantity of each kind of work done at the respective rates stated in the schedule, whether such quantity shall be more or less than scheduled, subject, however, to the total amount of the contract not being increased or diminished by more than [25] per cent. Any work ordered, but not scheduled, must be carried out and paid for under Clause..........of the "General Conditions of Contract."

MATERIALS.

Cement.—All cement used is to be the best high-burnt Portland, of approved brands and manufacture, well packed in strongly made casks or good bags, and delivered in packages, with the name of the manufacturer plainly marked thereon, in thoroughly sound condition, fit for immediate use without seasoning or air slaking, free from any sign of staleness, caking, or hard lumps; and no cement is to be used until it has been examined and approved of by the Engineer or his representative. As many samples as the Engineer may consider necessary may be taken from the various packages from each parcel brought on the works, and submitted to the following tests:—

(1) Fineness.—When passed through a sieve made of .0044 inch diameter wire of 5776 meshes per square inch, a residue of not more than 3 per cent. must be left on the sieve, the shaking of which is to be continued for the period of fifteen minutes.

(2) Tensile Strength.—Cement, when mixed neat with water, to give a tensile strength of not less than 400 lbs. per square inch after seven days' setting in water, the stress to be uniformly applied, increasing at the rate of 100 lbs. in twelve seconds, and the average of six briquettes to be taken.

(3) Time of Setting.—Neat cement shall develop initial set in not less than thirty minutes and not more than two hours. [Quick

setting cement is not recommended for pavement work, but, if it should be required, specify that initial set must develop in not less than ten nor more than thirty minutes.]

(4) Soundness.—Neat cement gauged with water to a stiff paste, in pats about 3 in. diameter, ½ in. thick at the centre and tapering to a thin edge, on glass, will be kept in moist air for twenty-four hours, and then immersed in water; these pats must be absolutely sound, and without air cracks or any signs of blowing at the end of seven days.

Should the samples, or any of them, fail in any one of these tests, the Engineer may reject the whole parcel from which they were taken, and the Contractor shall at once remove it from the works at his own expense.

All empty casks must be at once destroyed. The Contractor is to provide approved gauge boxes for measuring cement. The Contractor shall furnish to the Clerk of Works a duplicate delivery ticket for each load of cement delivered on the works. The ticket must be signed by the supplier of the cement, and be of such form and contain such particulars as the Engineer may decide.

Sand must be siliceous, coarse, sharp, clean and free from loam, clay or other foreign matter.

Stone used as aggregate must be good sound, hard basalt, granite, limestone or other hard rock approved by the Engineer, broken to gauges as under, and well screened, free from dust, dirt, or other foreign matter. Metal is to be of 2in. ring gauge, with all stone below ¾in. ring gauge screened out. Screenings are to be not larger than ¾in. gauge or smaller than ½in. gauge.

Woodblocks are to be of the best quality of red gum, jarrah, or other approved timber [See § 240 for suitable woods], thoroughly seasoned, free from dead heart, sapwood, shakes, gum veins, large knots or any other imperfections. They are to be cut from sound, well-grown trees, and clean sawn exactly to the dimensions specified. The logs will be sawn into planks of 7in. to 9in. wide by 3in. thick, the planks again being sawn into blocks exactly 5in. long. Blocks cut from different sorts of wood must not be mixed in the pavement, but each particular kind must be brought on the works, stacked and used separately from the others.

Tar.—This will be coal tar of the best quality, containing at least 50 per cent. of pitch and not more than 3 per cent. of water.

Closing the Roadway.—Before any length of any street is, for the purposes of this contract, closed to traffic, the Contractor must arrange to have an ample supply of materials of all kinds to carry out the work on that particular length without any avoidable delay, and he must also satisfy the Engineer that he has secured the services of a sufficient number of workmen for this purpose. All cement, woodblocks, and tar must be protected from the weather, so as to be, when used, in the best possible condition. In closing any portion of any street against traffic, sufficient space will be provided on one or both sides of the area to be paved to serve as stacking room for the materials to be used in the work, that is to say, rather more than half the roadway will be closed with or without a portion of the footpath as well.

Excavation.—As soon as any portion of any length of street has been closed to traffic, the Contractor must securely fence off same. The fencing is to be in accordance with type shown on drawings. During the whole of his operations the Contractor is to afford all such facilities as the Engineer may consider reasonable for ingress and egress of vehicles to and from premises whose only access is by way of the street under construction. This is to be accomplished by the provision of temporary approaches to gateways, and by allowing vehicles to use the same tracks as are used by his own carts and wagons. In breaking up the old road, the Contractor must provide adequate hoardings to prevent injury to passengers, horses or vehicles on any parts of the road still left open, or to windows or any other parts of buildings fronting same. The use of blasting powder or any other explosive will not be allowed. He will be responsible for any damage or injury resulting from any of his operations. The cost of all fencing, hoardings, all other structures for the protection of the public while the work is in progress is to be considered as included in the scheduled prices for the various classes of work. The Engineer may order the work to be started at not more than (three) points, and to be carried on from each point in any direction that he may consider desirable. As soon as fencing off has been completed, the existing metal road will be broken up for half its width, and the material resulting therefrom, which is to remain the property of the Council, will be carted away and stacked in heaps on the corporation depot, shown by locality plan. For the purpose of breaking up the metalling, the Council will give to the Contractor the use of a steam roller fitted with a scarifier, at a uniform charge of 5/- per hour, the Council finding everything in connection with the roller, and the Engineer to decide on the number of tines to be used in carrying out the work. Should any metal be necessary for the purpose of making connections between the new wood-blocking and the existing road at the end of the work, the Contractor is to free the metal obtained from the existing road from all fine stuff, dust and dirt, by passing it through a screen with bars having 2 in. openings. The screenings will be laid aside on the depot for future use. Below the original metal, excavate, as per drawings, to formation level, and cart the soil to the low ground, coloured green on locality plan, and there deposit it as filling to the depths ordered, and trim the surface. Any pitchers, disused pipes or other materials found in any part of the excavation will be removed with as little injury as possible, carted by the Contractor to the corporation depot aforementioned, and there stacked in separate heaps. The Council will, at their own expense, make arrangements for the removal and relaying of all water, gas, electric light mains, and sewers that may interfere with the work of the contract. The Council will have this work carried out as promptly as possible, but will recognise no claim by the Contractor for delay on account thereof, and the latter must afford every facility for the execution of such work. Any service pipes from gas or water mains which may interfere with the works of the contract must be altered by the Contractor at his own expense. All fire plugs, manhole covers, valves, cocks, etc., must, where considered necessary by the Engineer, be altered by the Contractor at his own expense to suit the surface of the woodblocking, he making all necessary arrangements with the proper authorities. All holes from which stumps, rocks, roots, old pipes, etc., have been removed must be refilled with earth of the same description as that surrounding the holes to be filled, and the filling must be consolidated by ramming, so as to be of the same density as the natural soil adjoining. Should it be found on opening up that any length of the work requires, in the opinion of the Engineer, a thicker foundation of concrete, and consequently an increased quantity of excavation, the formation will be altered as may be directed, and the extra excavation arising from the change will be paid for at the scheduled rate. At any place in the formation where, in the opinion of the Engineer, the ground is unduly weak, the Contractor is to excavate to the depths ordered and to refill and consolidate, as in the case of stump holes, etc., mentioned above. All such refilling and consolidation of stump holes, etc., and weak ground will be measured up as the work proceeds, and paid for at the rate mentioned in the schedule. Before commencing to lay concrete the formation must be cleaned up by the Contractor and approved by the Engineer. [Should there be an electric or cable tramway on any road on which woodblocking is to be laid, there should be a clause in the specification providing that the Contractor is, in carrying out his work, to take special care not to interfere with the running of the cars, and to make provision for the safety of the tramway works from injury by reason of any of his operations. Again, if the Council has no convenient depot, or no low ground to fill, it may be more economical and convenient for the Engineer to draw the specification so that all surplus metal and spoil shall become the property of the Contractor, and be disposed of by him at his own profit or at his own risk and cost as the case may be. If the material so to be disposed of has any value, the Council is pretty certain to get the benefit of this in the prices fixed by competing tenderers. Under certain conditions it may be necessary for the sake of drainage to put down a layer of gravel or metal under the concrete foundation, in which case this would have to be specified and paid for at scheduled rates.]

Concrete Foundation.—Concrete foundation for the woodblocking will be constructed to the dimensions shown by the drawings, or to such other dimensions as may be ordered by the Engineer, and in the following manner:—

The concrete will be composed of one part by measure of Portland cement, two parts of sand, one part of screenings, and three parts of metal, all as described above. These will be mixed with such proportion of water as may be directed by the Engineer, either in an approved mixing machine, or, if by hand, on a proper board platform in the following manner:—The stone, sand and cement will be laid dry in layers on the board, the metal being below and the cement on top; the whole will then be turned over twice in a dry state. The water shall be added with a watering can, and the stuff turned over at least twice in a wet state, or until, in the opinion of the Engineer, it has been thoroughly mixed and is fit to go into place. It must at once be laid on the formation in one layer, so as to finish, when floated, to the thickness shown by drawings or ordered, and well rammed with an approved flat-faced iron rammer. The concrete will be mixed in such batches as to allow of its being put in place quickly, and in no case must it be laid after a longer interval than twenty minutes from the time when the water was added. Care must be taken to make the top of the concrete even, so as to receive an even floating coat of practically uniform thickness. To secure a good bond between any concrete which has set and that which is to be newly laid, the surface of the old work must be well cleaned, hacked and wetted, and painted over with a grout of neat cement and water before the addition of fresh material. The top of the concrete layer is to be rendered and floated with a thin coat of mortar, composed of one part of cement to two parts of sand, true to grades and cross sections, to receive the woodblocking. In rendering the concrete, care must be taken not to disturb its setting. After floating, the surface of the concrete must be kept moist for at least seven days. When the Engineer shall have passed the concrete foundation as having been satisfactorily constructed and sufficiently set, the laying of the woodblocks is to be proceeded with and carried on without delay.

Laying Woodblocks.—It is to be understood that the laying of woodblocks must proceed in dry weather only, as it is important that the timber shall be dry when dipped and when put in place. Before being laid the blocks are to be dipped in boiling tar, of the quality described above, and set on the concrete foundation with close joints and with the fibres of the wood vertical. Except at street intersections, they are to be laid with their longest dimensions as nearly as possible at right angles to the line of the street. The joints of the rows are to be broken not less than two inches, and all closers are to be sawn to the proper length and not split. At street intersections they will be laid diagonally, as drawn, the mitred blocks being truly sawn to form close joints. All blocks are to be driven close together with a wooden mallet, and every sixteenth course lined up. Gutters or water tables will be formed according to the drawings, or as may be directed, as the work proceeds Expansion joints, filled and pressed with approved pugged and tempered clay to a thickness of 1in., are to be provided, one on each side of the road and one in the middle, for the full length of the paving. The cost of the expansion joints and their filling is to be included in the scheduled price for woodblocking. To connect the grades of the old and the new work, the Contractor shall take up and reset, in the same manner as at present, as much of the former as may be shown on the plans, or as the Engineer may direct, and this work will be paid for at the scheduled rate. All existing pavements that may be taken up and reset are to be well tarred and sanded, as in the case of new work, the cost being included in the scheduled price for relaying. As soon as possible after the blocks are laid, and when the wood is dry, the surface is to be thickly coated with tar, and on this coat of tar is to be sprinkled a coat of thoroughly dry sand. The mixed tar and sand will then be at once thoroughly swept into the joints of the pavement, so as to form a watertight grout. Before the close of each day's work all the blocking set during that day must be tarred and grouted, care being taken that the blocks last laid shall be secured so as not to be displaced by the grouting. Transversely across the street, as well as at intersections, expansion joints ¾in. in width are to be provided at intervals of thirty feet, and these again are to be filled with clay, as described above. Connections with existing pavements at ends of new work will be arranged in accordance with sketches and directions which will be given by the Engineer. The alignment of the courses of the pavement may be varied by the Engineer as the work proceeds, and the Contractor shall have no claim for extra payment on account thereof. The work of block-setting must not be carried on in showery weather, and in the event of rain threatening unexpectedly all blocks set must be at once tarred and sanded. All questions as to the suspension or otherwise of the work, on this or any other account, shall be decided by the Engineer, whose decision shall be final; but for every such suspension the Contractor shall be allowed a corresponding extension of time for the completion of the work, anything contained in the General Conditions notwithstanding.

Repair of Damage.—Should any kerbing, flagging, channelling, etc., be displaced or injured by carrying out the work of the contract, the Contractor is, at his own expense, to thoroughly reinstate the same, putting them in as good condition as they were in before the operations were undertaken. All damages to water, gas, electric light mains or sewers shall also be reported immediately to the respective authorities, so that they may have an opportunity to shut off and effect the necessary repairs, which must be paid for by the Contractor.

Opening for Traffic.—On the completion of any length, the Contractor shall remove all fencing, hoarding, surplus material and rubbish, and shall leave the wood pavement clean, except that it shall be covered with a coat of sand ¼in. thick (1 cub. yd. to each 144 sq. yds.), and ready for the resumption of traffic.

Maintenance.—The Contractor shall, at his own expense, maintain the works of the contract in good order and condition for a period of six months. The deposit security will be retained by the Council until the Engineer shall have certified that the work has been satisfactorily maintained in accordance with the specification, when the amount will be returned to the Contractor.

SCHEDULE OF QUANTITIES AND RATES.

No.	Quantities.	Description of Work.	Rate.	Amount.		
				£	s.	d.
1	......Cub. yds.	Excavation of present crust and earth below same down to formation level on drawings, including disposal of material, complete as specified, at per cubic yard ...				
2	......Cub. yds.	Extra excavation in addition to that shown by drawings, complete as above, at per cubic yard				
3	......Cub. yds.	Excavation and refilling stump or root holes or other voids, weak spots, &c., complete as specified, at per cubic yard				
4	......Cub. yds.	Concrete in foundations as per drawings or as may be ordered as per specification, at per cubic yard... ...				
5	......Sq. yds.	Woodblocking, laid, tarred, grouted and sanded, complete as specified, at per square yard				
6	......Sq. yds.	Taking up and resetting existing roadway abutting on new pavements, complete as specified, at per square yard				
7	.... Days	Labourer in opening up or any other work, at per day of 8 hours		*		
8	Item	Provision for extra work as per clause .... of General Conditions				

* This amount will vary with the estimated cost, &c., of the works.

249. Concrete Roadways.—Concrete road surfaces are very little known in this country, although the material has been long and extensively used for footpaths, particularly in New Zealand cities and towns. In Richmond, U.S.A., concrete roadways have been a great success when laid in the manner described below, and illustrated in Fig. 85.

The earth foundation is prepared and rolled in the usual manner, true to cross section. Gravel or broken stone is spread and well rolled to a thickness of 4 in. should the foundation be at all weak or in need of drainage. On this, or alternatively directly on the earth, is spread a layer of Portland cement concrete, in proportions 1-2-4, 4 in. to 5 in. thick, finished truly to crown and grade, parallel to the finished surface of the road, and 3 in. to 4 in. below it. When sufficiently set, the concrete foundation is sprinkled with fine sand, afterwards raked off by hand with a flat board rake, so that low places and inequalities are just filled. A layer of thin tarred paper is laid upon this to act as a separating joint. Upon the tarred paper is laid the concrete pavement 2 in. to 3 in. thick, composed of one part cement, two of sand, three of gravel, and two of crushed stone in a rather wet mixture. The wearing surface is composed of one part cement, one of sand, and one of clean stone or granite screenings mixed wet and laid to a thickness of 1 in. in two layers of ½ in. The first is well rammed, and the upper one is floated in, steel trowelled to ensure solidity, but finally finished with a cork trowel, leaving the surface with a sandstone finish. It has been found that the glass face left by steel trowels renders the road unduly slippery, whether wet or dry. When a section is finished the surface is covered with bags, and in dry weather kept moist for five days by sprinkling with water. The object of the

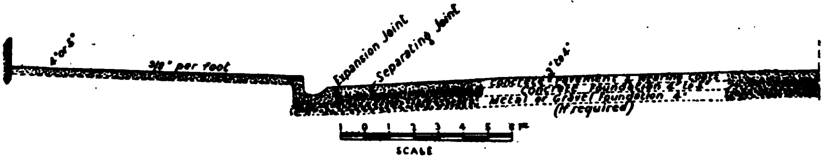


Fig. 85.

Half Cross Section of Concrete Pavements for Roads and Footpaths.

tarred paper separating joint is to facilitate repairs to the surface; without it the full depth of the concrete has to be broken up in the event of repairs being required.

In Richmond, U.S.A., the usual method of repair is to break off the crust, crush it, and relay with added cement and sand.

Joints to provide for expansion and contraction were tried, but declared unnecessary; in fact, a disadvantage, because the concrete wore off at the edges. Roads of this class subjected to heavy traffic for eleven years are reported to have stood remarkably well, and to have required practically no expenditure on maintenance. Concrete roadways in Toronto, Canada, have been successful. The surface is finished by floating with wooden floats after it has been cut by grooves into blocks about 5 in. x 10 in. to improve the foothold. The pavement is divided into sections about 20 ft. square by ¾-in. joints of paving pitch, so as to provide for contraction or expansion, and so prevent cracking.

250. **Khleinpflaster.**—A compromise between macadam and stone pavement termed *Khleinpflaster* has been introduced for much-used rural roads in Germany. A strip of this construction has been laid in Liverpool, but no instance of its use in Australasia has been recorded. The foundation course consists of pyramidal stone or spalls 4 in. to 8 in. square, by about 7 in. deep, placed head downwards. Into and above the interstices of these ordinary broken metal is spread to a further height of 4 in. to 5 in., then rammed and rolled to a total depth of about 10 in. Over this sand is spread to a thickness of 1 in. On the foundation thus completed selected broken stones, preferably 3½ in. to 4 in. square, and 3 in. to 4 in. deep, are carefully placed as close as possible to one another, not more than ½ in. apart, with the smooth face uppermost. The interstices are filled with a kind of lime-sand, mortar binding, which does not disintegrate, and the whole is rolled till the surface is smooth. The stones are not laid in regular lines across the road, but in a series of semi-circular courses 4 to 5 ft. across. The general appearance of the road is that of a large mosaic pavement. The life of these roads is stated to

be twenty-five to thirty years, after which time resurfacing is required, though the foundation remains as good as ever. Minor repairs cost about 1d. per square yard per annum.

Captain Bingham* gives the cost in Germany as 7s. per square yard, of which 3s. 4d. is chargeable to the foundation. If an old road foundation can be utilised, as is very often the case, the average cost of a pavement of this kind is about 4s. 10d. per square yard, of which one-half is set down for rectification of the former foundation. A road strip 16 ft. wide could not be built, in this country, for less than £2400 per mile. The cost, though high, is a considerable saving on a wood-paved road involving the outlay of, say, three times that amount.

251. Stone Block Pavement.—For general utility, cleanliness and comfort, stone pavements do not compare favourably with wood blocking for business or residential streets. In old-world cities, including London, the favourite pavement, until quite recently, was one of blocks of stone, preferably granite. Modern pavements, including wood blocking and asphaltum, are gradually replacing stone blocks, but even yet the majority of the roads are of the old type. In Australasia pitched streets have never been popular, because of their slippery and noisy nature. The first cost being comparatively low as compared with that of wood, with its attendant concrete foundation, stone blocks have their place in locations where the traffic is heavy, but not of a class to warrant one or other of the more expensive high-class pavements. For lanes and wharf roads they are admirably suited, and it is in such situations that they are usually found.

252. Quality of Stone.—Stone blocks should be of rock sufficiently hard to resist abrasion, and tough enough to withstand fracture under very heavy loads. The very hardest stones, however, though exceedingly durable, usually wear smooth and become slippery.

Fine-grained granite makes the best paving material, and is generally preferred for such when obtainable at moderate cost. A feature of granite rocks is the facility with which they can be split along three cleavage planes at right angles to each other, comparatively little dressing being required. Trappean rocks possessing no well-defined cleavage planes do not lend themselves to smooth or even cheap pitchers, though the stone is particularly capable of resisting abrasion. Basalt makes a very good pitcher, and is, in Australia, more used than any other rock, scarcely anything else being seen in Melbourne and Sydney. Sandstone and limestone, being generally too soft, are but little used in paving work.

---

* Report to the Royal Commission on Motor Cars, 1906

253. **Size of Paving Stones.**—For street channels and lightly-trafficked lanes the stones are usually dressed to 9 in. wide, by 10 in. to 14 in. long on the face, by 5 in. to 6 in. deep.

Where the traffic is constant and heavy, sets are substituted for pitchers, the sizes being about 4½ in. wide by 12 in. long, by a depth of from 5 in. to 9 in. Sets are superior to pitchers, for the reason that the stones being smaller are less liable to tilt under eccentric loading. Furthermore, they afford a better foothold, and because they do not wear so round, are less noisy. Sets should always be used in preference to pitchers on steep gradients. Stone blocks should not be tapered more than specified in § 261.

254. **Foundation.**—In little-used lanes it is generally sufficient to bed the pitchers or sets on not less than 3 in. of sand or engine ashes, provided that the earth below is fairly well drained. On heavily-trafficked roadways observation discloses the fact that the surface of paved roads so founded sinks unevenly, and that the result is anything but satisfactory, requiring far more attention than if laid on a more secure foundation. Stone pavement is no exception to the rule that the foundation can never be too sound, for it, after all, carries the load. Concrete 6 in. to 9 in. thick should be generally adopted as a foundation where the traffic is very heavy. For specification see § 248.

255. **Cross Section.**—The profile in cross section is usually curved. The Crown can be computed by the formula and table in § 243, but should be a minimum of 3 in. Rights-of-way and lanes are frequently constructed hollow in their centres to permit of these being formed into channels for the discharge of

drainage waters. The concavity depends upon the volume of water to be dealt with, but should not exceed 3 in. in a lane of 10 ft. wide unless for very special reasons.

256. **Laying the Pavement.**—Stone blocks should invariably be set on a sand or cinder bed. Even with a concrete base a 2-in. cushion cannot be omitted, as the pitchers or sets, unlike wood blocks or bricks, are of more or less irregular depths. The stones should be set with the aid of a line stretched tight, parallel to the grade, and as much above it as the probable sinkage under the rammer, or alternatively with the aid of a template or straight edge. They are generally laid in uniform courses transversely to the line of maximum traffic, but break of joint is most important. Thorough ramming is essential to success, more particularly when the concrete foundation is omitted. Stones that do not conform to the finished level when rammed should be lifted, reset, and rerammed after a little of the bedding material has been removed or inserted. To ensure an even surface the joints should be as narrow as possible—as a rule about ½ in. wide at the surface, but rarely more than ¾ in. Closer jointing can for obvious reasons be obtained only with well-dressed stones.

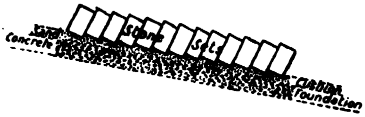


Fig. 86.
Method of Laying on Steep Gradients.

On steep gradients additional foothold is secured by laying the sets with a slight inclination down hill, as shown in Fig. 86.

257. **Grouting.**—Joints are usually raked out to a depth of at least 3 in., after which they are grouted with cement mortar, lime mortar, tar and sand, or, best of all, with some bituminous composition. Sand alone as a grouting material is unsatisfactory, and should never be permitted. Portland cement swept in dry and afterwards sprinkled with water from a fine rose makes an excellent grout where the pavement is not subjected to heavy loads, but where it is liable to be fractured, the use of this material cannot be recommended, since joints once fractured never reunite. Lime mortar is less objectionable in this respect, though inferior to tar and sand grout. Probably the best filler is a mixture consisting of four parts by

weight of pitch and one part of tar thoroughly boiled together, and poured while hot into the joints from the spout of a watering can. About 2 gallons of the composition are required for each square yard of paving with sets, and correspondingly less with the large-sized pitchers. Tar and sand or bituminous grouting must be carried out in dry weather, but dull or drizzly weather is better than any for cement or lime filling.

258. Paved Roads in Very Sandy Ground.—Fig. 87 shows the pavement of portion of the Williamstown Short Road, Victoria, as designed and successfully built by Messrs. Champion and Heath in collaboration.

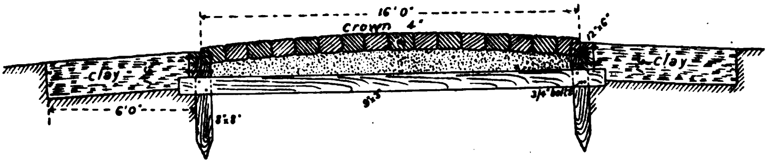


Fig. 87.

Paved Road in very Sandy Ground.

The sand beneath the pavement is confined by wooden kerbing liberally backed by clay filling. On less important roads kerbing and ties can be omitted, and the clay backing relied upon to prevent lateral displacement of the sand under the pitching.

Mr. Harry F. Johnston, Surveyor-General of Western Australia, informs us that at Wanneroo, W.A., roads in sandy country have been treated by pavement with wood blocks about 9 in. deep, and 1 ft. to 2 ft. in diameter, mostly of jarrah, cut close to the site of the works. There are about 15 miles of such roadways in the district, and they are said to be durable and effective, though very rough.

259. Cost.—When pitchers cost 25s. per 100, and average 12 in. in length, the cost of paving and sand bedding, exclusive of excavation, is about 3s. 6d. per square yard. The cost of maintenance varies between 1d. and 3d. per square yard per annum, depending on the solidity of the foundation and the volume of traffic.

260. Durability.—Basalt pitchers have been known by Mr. Mountain to wear in Melbourne at the rate of 4-10 in. per annum under particularly heavy traffic in Flinders-street, close to the wharves. Ordinarily the efficient life of a well-laid pavement of this material in a city lane is at least eighteen years, while in comparatively little-used rights-of-way they will not, if well maintained, wear out for forty or fifty years. Basalt sets may be used on grades even steeper than 1 in 10, though pitchers on such an inclination would be slippery and dangerous. Granite blocks become rounded and slippery rather than wear out; they are not so satisfactory on steep gradients as softer stones, including basalt. In any situation granite blocks make a rough, noisy road after a few years' wear.

261. Example of Specification for Stone Pavement:—

SPECIFICATION referred to in foregoing Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement, and to be observed in the laying of about..........square yards of squared paving in the positions shown on locality plan.

General Description.—The works of this contract consist of the excavation and consolidation of the sub-surface to an even formation, the laying of a layer of sand three inches in thickness, and the setting thereon and grouting of pitchers or sets, and all work incidental thereto.

Nature of Contract.—[As per woodblocking specification, § 248.]

MATERIALS.

Sand must be siliceous, coarse, sharp, clean and free from loam, clay or other foreign matter.

Pitchers are to be of the best basalt [or other specified stone], free from honeycomb or any other defects, 9in. wide on top, not less than 8in. wide on bottom, nor less than 6in. deep, and not more than 14in. nor less than 10in. in length, flat and smooth on top, and with substantially square arrises. [The depths of pitchers may vary from 5in. to 8in. in depth, according to importance of the work to be undertaken.]

Sets are to be of the best basalt or other approved stone, free from honeycomb or any other defects, 4½ in. wide on top and bottom, not more than 12in. long, nor less than 8in. deep, flat and smooth on top, with substantially square arrises. [The depths of sets may be varied between 5in. and 9in., to suit the conditions.]

Cement.—[If used, see specification for wood pavement, § 248.]

Concrete.—[If in an important work a concrete foundation is laid, the specification for wood pavement should be consulted. The surface of the concrete need not be rendered, but should be brought to a fairly even surface by ramming. On this a cushion of 2in. of sand is placed, upon which to bed the pitchers or sets.]

Excavation.—[See the clause relating to excavation in the specification for woodblocking, Chapter XII. It will need variation, in accordance with the class of squared paving to be undertaken.]

Setting.—Pitchers or sets are to be laid in uniform courses, with close joints, on a firm foundation of 3in. of sand or clean ashes, all courses to break bond not less than 4in. The whole is to be well rammed and back rammed with a pavior's rammer not less than 56lbs. in weight, and finished off to levels and grades shown on drawings, the whole to present a regular and even face after ramming. Cracked or chipped pitchers are to be replaced by sound ones. Gutters are to be formed as shown on drawings.

Grouting.—After ramming, joints are to be raked out to a depth of at least 3in., and thoroughly grouted with cement mortar, or tar and sand, as may be scheduled. Cement grout is to be composed of 1 part of Portland cement to 3 parts of sand. Tar grout to consist of perfectly dry sand thoroughly impregnated with boiling coal tar, reduced by sufficient boiling to the condition of medium pitch.

Maintenance.—[As per woodblocking specification, § 248.]

SCHEDULE OF QUANTITIES AND RATES.

No.	Quantities.	Description of Work.	Rate.	Amount.		
				£	s.	d.
1	......Cub. yds.	Excavation of all material down to formation level shown on drawings, including disposal of material, complete as specified, at per cubic yard				
2	......Cub. yds.	Excavation and refilling stump or root holes or other voids, weak spots, &c., complete as specified, at per cubic yard				
3	..... Sq. yds.	Squared paving set on 3 inch of sand, rammed, grouted with tar and sand, complete as per specification, at per square yard				
4	Item	Provision for extra work as per Clause ...... of General Conditions		10	0	0

Note.—If paving is to be set on a concrete foundation the schedule must be extended. See Wood Pavement Specification, § 248, for an example of what is required.

262. Brick Pavement.—Brick as a road pavement has for several reasons not as yet found much favour in Australasia. In the first place wood pavements are deservedly popular in city streets, where brick pavements are noisy and not sufficiently durable for heavy traffic. Further, we in this country are compelled to exercise great economy in municipal work, and broken stone roads are accepted as sufficiently serviceable for all but the heaviest traffic. On account of the almost infinitesimal demand, paving bricks of just the right quality for road works are not regularly manufactured.

In America brick pavements were first laid in 1870, and with such good results that most of the smaller cities of the Mississippi Valley now, owing to the high price of wood blocks of good quality, employ no other paving material. Throughout the United States the use of brick in residence and light traffic business streets is increasing at such a rapid rate that about 200 firms are now engaged in the manufacture of special paving bricks. The output of some of the plants reaches 100 million bricks per annum. The authors have had roadways where the traffic, though rather heavy at times, is not constant, paved, with very satisfactory results, with the best quality of machine-made building bricks.

While it does not appear likely that brick pavements will in the near future be extensively used on Australasian roads, engineers in practice may find situations in which they are suitable, and some notes on the subject are likely to prove useful.

263. Quality of Brick.—Too much stress cannot be laid on the necessity for employing for street work properly annealed bricks, made from material consisting essentially of silicate of alumina, which will not melt into glass when subjected to intense kiln temperatures; the clay must not contain more than 1 per cent. of lime. Methods of manufacture vary with the material, but are very similar to those employed for building bricks, except that the bricks are burned just to the point of fusion, the process extending over a period of from ten to fifteen days; gradual cooling is necessary to ensure toughness. The best bricks are harder than glass, though slightly softer than quartz. To use bricks that are at all friable and underburnt is simply to court disaster. In America paving bricks are subjected to severe abrasion and absorption tests before acceptance.

264. Foundation.—The very best foundation is undoubtedly secured by the use of a layer of concrete of uniform thickness, the upper surface of which should be floated in with cement mortar, as with wood blocking. The thickness should not be less than 5 in., but a mixture particularly rich in cement is quite unnecessary. Concrete in proportions 1-2-5, or even 6, will generally suffice, and the use of a greater quantity of Portland cement is unwarranted, except in situations where the sub-grade is soft and wet. Where advantage can be taken of an existing metalled or gravelled surface, the addition of a layer of 6 in. to 9 in. of gravel or broken stone properly used will afford a fairly satisfactory foundation. Care must be taken to spread the gravel evenly in layers of 3 in. or 4 in., well rolled. Should it be dumped in heaps, and merely levelled off between, no amount of rolling will make a satisfactory job, as the roller will ride on the heaps without compressing the material between them, so that subsequent settlement and inequalities in the surface are inevitable. The importance of even spreading and thorough rolling cannot be overestimated, and for this purpose steam or motor rollers are superior to any other type.

265. Laying the Bricks.—The wearing course of bricks is invariably laid on edge, and generally on a cushion layer of sand 1 in. to 2 in. thick to secure a uniform bed. The cushion should be evenly spread, with its surface parallel to the finished pavement, and levelled off by a wooden template. The bricks should be laid as close as possible, with the courses breaking joint, and care should be taken that very hard or very soft bricks are excluded, as they will not wear uniformly. Rolling of the pavement is essential, and for the purpose a 3½-ton motor roller, such as described in § 112, is best. Heavy steam rollers are apt to tilt the bricks on the first traverse.

266. Filling the Joints.—Sand, tar-grout, and cement-grout are in common use as joint fillers. Sand is fairly satisfactory when well swept in, at a total cost of about 1½d. per square yd., but does not prevent the chipping of the edges. Distilled tar, to which 10 per cent. of Trinidad pitch is added, if applied at a temperature of about 300 deg. from the spout of a watering-can, costs at least 6d. to 7d. per square yd., and is troublesome to work. Cement is most generally used in the form of a grout about the consistency of thin cream, with about equal proportions of Portland cement and fine sand first mixed dry. The pavement must be watered, and the grout constantly stirred as applied. The mixture is swept in with steel brooms till the joints are fully filled, after which the whole is covered with half an inch of sand, kept watered at intervals of about two days, the time depending on the weather. Traffic must not be permitted on the pavement for at least a week, for should the joints be fractured the result is failure. One barrel of cement suffices for about 30 square yds., and the total cost of filling the joints by this method, including sand covering and cleaning up, is about 6d. per square yd. Cement-grouted pavements are certainly more noisy than those grouted with either sand or tar.

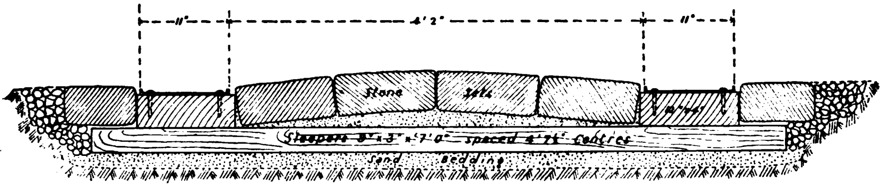


Fig. 88.

Cross Section of Steel Wheelways, formerly laid in the vicinity of Melbourne.

267. **Steel Wheelways.**—What are probably the oldest steel plate wheelways of any considerable length in Australia were laid between 1880 and 1890 on several of the main roads approaching Melbourne. The form of construction then adopted, and followed in later tramway works, is shown in Fig. 88.

As pointed out in § 19, this type of tram line is expensive; the timber is perishable, and trouble is experiencd as the result of cold rolling and temperature variations.

A new type of rolled steel wheelway, introduced by Messrs. Lohmann and Co., and adopted by Mr. A. C. Smith, engineer to the Shire of Moorabbin, Victoria, promises to give excellent results at moderate cost. Some hundreds of miles of track of this description have been laid in Germany. Figs. 88a and 88b show the section adopted, and the method of jointing by fishplates with through bolts. The rails are inverted, and filled with concrete before being placed in position on a previously prepared bed of concrete.

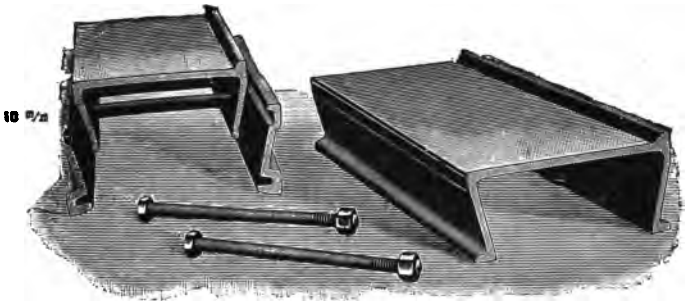


Fig. 88a.
Rails for Steel Wheelways, showing fishplates and bolts.

Timber ties are not required, as the weight of the concrete-filled rails, combined with the rigidity secured by tightly bolting up the fishplates, prevents lateral displacement. Paving between the plates is desirable, though not absolutely essential. The cost in Australia of plates 7 in. wide, exclusive of flange, is about £855 per mile of track, and the total cost of the completed wheelway £1100 to £1200 per mile. The extra cost of 11-in. rails is approximately £400 per mile.

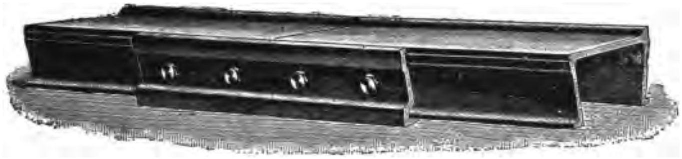


Fig. 88b.
Rails, as jointed.

267a. Cost.—A brick pavement of considerable area, laid complete with a 5-in. concrete foundation, costs on the average about 10s. per square yd., inclusive of a moderate amount of excavation. For the cost of brick paving on sand foundation see § *292*.

CHAPTER XIII.

THE DUST PROBLEM.

268. There is no questioning the fact that ophthalmic, pulmonary, and respiratory complaints are, to quite a large extent, caused and disseminated by a dust-laden atmosphere. Dust arising from public highways is almost invariably composed in part of putrescing particles in suspension, accompanied at times by germs of typhoid, tuberculosis, and other zymotic diseases. It may be said to affect the comfort of all classes of the community, and the pockets of not a few. Shopkeepers more especially suffer at times large losses by damaged goods.

Dust in its worst form is encountered in Australia, more particularly in the arid interior, and in districts subjected to hot winds comparable with those of the Sahara. Humidity of air largely reduces dust. For instance, if the road conditions be similar, humid cities like Sydney and Brisbane suffer less therefrom than Melbourne and Adelaide, where the air is generally much drier. While it must be admitted that no practicable measures can be undertaken for the complete suppression of dust in a place like Broken Hill, in the throes of a drought laying waste the whole country side, there is no good reason why much should not be done in towns more favourably situated, and with ample unfailing supply of water. The fact remains, however, that the dust nuisance is extremely acute in most parts of Australia, and that much work lies before municipal engineers in devising and putting into operation schemes of relief from this scourge. The duty of providing funds sufficient to cope with the question devolves upon the municipal councils, and should not be shirked, as it often is.

269. Road Dust.—Although a certain amount of dust is blown on to roads from adjacent gardens and back yards, the principal supply in cities is derived from the abrasion of the materials used in construction by the agency of horses' feet, and by narrow sharp-edged vehicle tires. Sandy flanks of suburban streets are generally more or less grassed, and the grains or particles, being comparatively heavy, are not blown about to the same extent as finely-powdered materials resulting from constant attrition, which are lifted and kept in circulation by wind. Dust therefore implies waste, and any scheme for the mitigation of the dust nuisance that does not aim at the reduction of wear is obviously wrong in principle. Other sources of dust include horse droppings and garbage generally, which in cities are swept up in a more or less efficient manner, and removed from time to time, generally in open carts. The abominable nuisance created by the removal of garbage and sweepings in open carts, especially on windy days, seems to be tolerated, for some unknown reason, in most Australian towns and cities. In this respect there is room for radical improvement in the design of carts or wagons used for the purpose.

270. Motor Traffic.—Although motor cars do not create dust to any considerable extent, there is no vehicle frequenting the public streets capable of raising it in the same large quantities. In fact, were it desired to construct a dust-raising machine, it would be found that a high-speed modern motor car possessed most of the necessary qualifications. Recent improvements, from a mechanical point of view, intensify the dust-raising capabilities, more especially as regards the greater suctional qualities of the enlarged pneumatic tires, which of late have been almost doubled in section. Motor cars raise more dust from a rough road than from an equally dusty, but smooth, one, the speed being equal on each. The real trouble, however, lies in the speed at which motors are commonly driven. The tire surface speed, and that of the flow of air under a car travelling at 30 miles per hour, is equivalent to 44 ft. per second. The result of such a rush of air, combined with the suctional action of the tires and the partial vacuum created at the rear of the vehicle, is to raise clouds of dust if any be present on the road. It is considered that a speed limit of 15 miles per hour on lightly trafficked suburban roads is a fair one from all points of view. Experiments made in England go to show that cars on high wheels, with the chassis well clear of the ground, especially at the rear of the car, are less dusty than others; also that tool boxes, mud-guards, &c., near road level raise dust in large quantities. The form of chassis that disturbs and raises dust less than any other is smooth and boat-shaped underneath.

271. General Principles.—That absolute freedom from dust can never be secured in climates such as are met with in Australasia is certain. The practical solution of the difficulty appears to lie in the adoption of better construction and better and more complete maintenance methods, on common-sense lines, rather than in experimenting with dust-preventing compounds on roads, which can never be satisfactory pending reconstruction. In other words, an effort should, in the first instance, be made to prevent as far as possible the formation of dust on the road surface. Palliatives designed to hold in place and render unobjectionable such dust as will be formed in spite of all precautions are then of secondary importance, and their use may or may not be required as the situation and importance of the road or street demands. When it is remembered that a stone which wears twice as long as another, produces approximately half as much dust, the necessity for a wearing coat of the very best material obtainable at reasonable cost becomes apparent. Local material can generally be found for foundation purposes when a road is constructed, but it is not always good policy to use the cheapest stone for the final coat. The argument applies not only from the dust-producing point of view, but as a general principle of economics, already discussed in preceding chapters. In addition, the fact that dust of the summer becomes, after rain, almost equally objectionable mud, must be borne in mind. The use of weak gravel is a prolific source of dust in suburban and country roads, and material of this class should be rigidly excluded from use under all conditions. In fact, gravel should never be permitted in the wearing surtace of roads contiguous to any large city, except as a binding medium, and then only when of undoubted quality. On the subject of gravel roads the reader is referred to Chapter VI. Another productive source of dust is the reintroduction of road scrapings or sweepings, or loamy earth of any description, as binding. See § 176. The necessity for care in the selection of binder material has been already dealt with in an earlier chapter. Resheeting without loosening the crust of the worn-out road is another extremely bad practice responsible in a large measure for dusty roads. Unfortunately, the fact that metal so spread is more often than not crushed and splintered under roller and vehicle wheels is not as yet generally appreciated. In these days of scarifiers and other modern appliances there is no excuse for neglecting this elementary consideration. Attention is here again called to the fact that hand-broken metal often contains too large a percentage of fines, which tend to produce a weak, and therefore dusty, roadway. A smooth surface is essential to cleanliness, otherwise dust cannot be easily removed when formed. The introduction of steam rollers has done much to ensure not only an even surface, but improved roads in many other respects. The more general use of these implements would go a long way towards mitigating the dust plague.

The wear of wood, asphalt, stone, or brick pavements is so slow as to be almost negligible. Dust arising from any of these surfaces is produced by extraneous matter, including horse dung and material brought, generally in the form of mud, by vehicles from tributary roads.

272. **Dust Palliatives.**—Methods at present in use for the suppression of dust may be divided into six classes, each of which will be dealt with at some length below—

1. Sprinkling with fresh water.
2. Sprinkling with sea water.
3. Sprinkling with artificially-prepared saline solutions.
4. Sprinkling with patented mixtures of water and saponified oil.
5. Impregnating the surface with crude oils.
6. Applications of coal tar products.

273. **Fresh Water.**—Fresh water evaporates very rapidly, and its use is at best only a temporary expedient. A serious disadvantage attending the use of water in liberal quantities on ordinary metalled roads is the fact that the surface, being unduly softened, is subject to rapid wear, and even to erosion when watered by a hydrant jet. Another important reason why watering is impracticable as a universal remedy is the

high cost, amounting to 1d. to 3d. per square yd. per annum, depending on the season and locality, of applying it at sufficiently frequent intervals, and, further, the absence of sources of supply in most country districts. It must not be understood that the utility of water in mitigation of dust is denied; what is contended is that in many situations there are cheaper methods whereby the main object, that is, the prevention of wear, can be accomplished, and that under such circumstances constant sprinkling is unnecessary. The use of water on city street pavements is recommended as much with the object of keeping them cool on hot days as for dust-laying. Frequent flushings render pavements of all kinds less slippery and more sanitary in every way; in fact, asphaltum roads become greasy and dangerously slippery unless frequently washed down.

274. **Sea Water.**—Salt, as is well known, is hygroscopic, that is to say, it becomes damp on exposure to moist air. Sea water for this reason gives better dust-laying results than fresh, because the salty residue remains moist. Salt water has been successfully used in Sydney for street watering for some years. The City Surveyor reports that road surfaces remain moist for a much longer period, and that one sprinkling with sea water is equivalent to about three with fresh. The use of sea water involves a separate service as well as a pumping plant, and is, of course, applicable under special conditions only. Sea water constantly applied is injurious to boots and shoes, and when dry the salt is said to affect the human throat and eyes, and to be bad for horses' feet. As used in Sydney no injurious effects have been reported.

275. **Saline Solutions.**—Acting on the principle that saline solutions are more effective than fresh water, a mixture of about 3 lbs. of calcium chloride with each gallon of water has of late been reintroduced in English inland towns. Calcium chloride is very like common salt, but, being more hygroscopic, absorbs moisture more freely. Being as yet practically a waste product, it can be obtained at a low price in England, but would be too expensive for general use in these States. It is applied from ordinary water-carts, and at least one appli-

cation each week would be required in a dry climate. The objections cited against sea water are equally applicable to artificial saline solutions.

276.. **Patented Mixtures.**—Most, but not all, of the patented mixtures on the market are in the nature of a fairly permanent emulsion of a soapy solution mixed with cheap petroleum or coal tar oil. The principal function of the mixture is to permit the easy distribution of practically non-volatile oils in a finely-subdivided state over road surfaces. Although quite largely used in England, they can be regarded only as expensive dust palliatives, liable to be washed away by rain at any time. Authorities well qualified to judge consider that, although they have their special uses, saponified oil mixtures cannot be accepted as wholly satisfactory dust preventatives.

277. **Crude Oils.**—The use of oil as a dust-layer has not, as yet, been a great success in Australasia. It was tried in Melbourne and Sydney, but its use has been discontinued on the score of expense. Mr. W. M. Gordon, City Surveyor of Sydney, in his report for 1905, stated that with oil at 3d. per gallon the relative costs for a definite service were £32 9s. 11d. for oil and £12 12s. 8d. for water, and wrote:—

"It appears to me that oil is eminently adapted for use on park roads, country roads, or in situations where a supply of water is difficult to obtain, but where water is obtainable in the street itself, and free of charge, oiling is more expensive. I am also of opinion that roads unravel quicker in the dry weather when oiled than with the use of water. In these circumstances I cannot recommend the further use of oil."

For more on this subject see § 90.

278. **Tarred Surfaces.**—Coating the top of the road with tar is a considerable advance upon sprinkling with any of the liquids mentioned above, for the reason that under favourable conditions surface wear is almost entirely arrested, and the formation of dust by attrition prevented. As regards dust, tar-painted roads can be classed with asphaltum surfaces. They are easily washed, and dry quickly, though the free use of water tends to perish the tar. The cost of application

ranges from 1d. to 2d. per square yd. per annum, depending on conditions. Recently improved methods, described in § 216, whereby tar is applied by means of a spray, in place of hand-brushing, promise to materially reduce the cost. Provided that the road surface comes up to the requirements mentioned in § 213, and the coating is properly carried out in suitable weather, we consider that tar painting offers the best and cheapest known solution of the dust problem for streets of light to moderately heavy traffic. Tar painting is likely to prove even more successful in this country than in the moist climate of England.

Tar macadamised roads are apt to wear unevenly unless coated with tar once, and in some cases twice, per annum. If not so treated they are no better than dry macadam as regards dust. The opinion has been already expressed that, provided surface wear can be prevented by tar painting, the use of tar macadam is a waste of money expended in tar buried beneath the surface to no useful purpose. The principal objection to tar macadam at all times is the fact that the voids between the stones are not properly filled, and the road is therefore incapable of withstanding heavy traffic.

279. Conclusions.—The following is a summary of the points to be attended to, in the opinion of the authors, with a view to the mitigation of the dust trouble:—

1. Carry out all road works on strictly scientific principles, under the supervision of well-qualified engineers.
2. Use the best materials, even if they have to be transported some distance.
3. Avoid the use of road or gutter sweepings and loam as a binder for metalled roads.
4. Extend the use of steam rollers and scarifiers.
5. Extend wood block or other suitable pavements where the traffic is very heavy.
6. Provide sufficient funds for road maintenance, flushing, and cleansing generally.
7. Tar paint roads and streets where practicable.
8. Provide a sufficient number of water carts, and use them.

9. Restrict the speed of motor cars.
10. Insist on tires of proper widths.
11. Insist on covered and vermin-proof garbage tins and vehicles.
12. Encourage tree planting as wind breaks.

After all these have been duly attended to there will still be dust, and sometimes a great deal of it, as anyone may easily realise who has seen a strong gale in dry weather moving sand and loam by thousands of tons from cultivated or grassless surfaces, such as those which in a dry summer practically surround the city of Melbourne. A glance at the map during a suburban drive will show that the area occupied by roads is usually small compared with the other areas not built upon and dust-producing.

It is therefore not at all fair to blame the roads for all the dust raised in any district.

CHAPTER XIV.

FOOTWAYS.

280. Earth and Gravel Paths.—The cheapest form of path consists merely of earth neatly trimmed and covered with an inch or more of gravel, which, if not naturally fine, must be screened. The most important consideration of all is the regularity with which the grading of the surface is carried out and maintained, so that water may be shed without collecting in pools. A transverse fall of about half an inch per foot gives the best results. Clayey paths can be improved by the addition of sand, which must, however, be well incorporated with the clay on the principles stated in § 79; otherwise it will blow away. Satisfactory paths can be made in loose ground by the mixing of gritty clay with the top few inches of sand, after which bluestone toppings are added in moist weather, then rolled and left to be beaten in by foot traffic. Toppings that have been damaged by wet are quite satisfactory.

281. Pavements in Use.—The following materials are in use in Australasia in cities and towns where pavements of a more or less durable nature are required:—

1. Tar pavements.
2. Cement matrix pavements. (a) Those laid *in situ;* (b) artificial flags.
3. Brick pavements.
4. Natural stone flags.
5. Asphalt pavements. (a) Mastic; (b) Trinidad mastic.

Each of these is described and discussed separately below.

282. Width of Pavements.—The widths and side slopes of the footways are discussed in §§ 163 and 164, Chapter IX., to which the reader is referred for detailed information on these points.

In important business streets it is for obvious reasons desirable to pave the full width of the path. In suburban residential streets the paving of a strip is generally sufficient, and is advantageous where tree roots would interfere with the improvements if carried to the full width, thereby largely increasing the cost of maintenance. Six feet is a suitable width for pavement strips, but in many places 4 ft. 6 in. suffices, especially if the inner edge is kept 9 in. from the fence line.

The practice that sometimes obtains of placing the pavement strip alongside the gutter in preference to the inner or fence side of the footway has little to recommend it. Pedestrians naturally walk close to the fence, which affords a certain amount of shelter from the elements, and constant traffic causes depressions to be worn on the unpaved portion. Water lodges in these, and forms highly objectionable pools in front of entrances to properties and in other places. The convenience of all is best served by placing the paved strip next to the fences.

283. Kerbs.—In important streets kerbs are required to hold up and protect the pavement. On country roads they are superfluous, and in residential suburban streets can generally be omitted if the gutter is paved to the cross section shown in Fig. 113. Kerbs are usually of natural stone, but concrete and vitrified brick are also used. Basalt, granite, syenite, and trachyte are satisfactory stones, and far superior to those dressed from limesone or sandstone.

The dimensions commonly adopted are given in the following specification. Some engineers prefer flat kerbs (see Fig. 81), such as 12 in. wide by 8 in. deep, or 9 in. wide by 6 in. deep. The objection to flat kerbs is that they are more liable to displacement unless laid on a concrete foundation. Though lighter, the superficial face to be dressed is practically the same as in deeper kerbs, while the saving in cost is trifling.

284. Example of Specification for Stone Kerbing:—

SPECIFICATION referred to in the foregoing Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement, and to be observed in the laying of about............lineal feet of kerbing in the positions shown on locality plan.

General Description.—The works of this contract consist of excavation for the reception of bedding, the setting of kerbstones, and all work incidental thereto.

Nature of Contract.—[As per wood blocking specification § 248.]

MATERIALS.

Sand must be siliceous, coarse, sharp, clean, and free from loam clay or other foreign matter.

Kerbing is to be of the best basalt or other approved stone, free from honeycomb or other defects, 12 inches wide on top and bottom, and 15 inches deep, in lengths of not less than three feet, bevelled if ordered to suit the slope of the path, medium axe-dressed for full width on top, for 10 inches on the face, and for 1½ inches on the back with squared ends. Circular kerbstones wrought to a radius on the outside of 2 feet 6 inches with ends radial, but similar in all other respects to the above, are to be used at corners. [For less important work, kerbstones 9 inches wide on top and bottom and 12 inches deep may be used.]

Excavation.—All earth, stone, or other substances are to be excavated to the depth necessary to form foundation. All excavated material, which is not used for refilling or making good weak places in the ground is to remain the property of the Council, and is to be removed by the Contractor and deposited where directed within ....chains of the site from which it was taken. The scheduled price for kerbing is to include all excavation and removal of surplus material.

Setting Kerbs.—Kerbstones are to be set on a firm foundation of three inches of sand or clean ashes, true to lines and grades, with close joints properly grouted and pointed with neat Portland cement mortar. The Contractor is to make provision for outlet pipes crossing the footpath, and pipes are to be cemented to kerbstones with cement mortar composed of one part of best Portland cement to two parts of sand. Pipes must be neatly cut off flush with the face of the kerb.

SCHEDULE OF QUANTITIES AND RATES.

No.	Quantities.	Description of Work.	Rate.	Amount.		
				£	s.	d.
1	......lin. ft.	Bluestone kerbing provided, set, &c., complete as specified, including all excavation, disposal of surplus material, &c., at per lin. foot				
2	Item	Provision for extra work, as per clause.........of General Conditions				

The cost of bluestone kerbing, 12 in. by 15 in., in accordance with the above specification, averages about 2s. 6d. per lineal foot, laid complete.

285. **Concrete Kerbs.**—These are made of reinforced concrete in combination with gutter inverts, in lengths suitable

for transport, or in plain concrete, as exemplified by Fig. 117, Chapter XV. Concrete kerbs, though perfectly satisfactory in most situations, are not so durable under rough usage as the best natural stones. Of recent years cast-iron kerbs have come into use in European cities, but they have not found much favour in Australasia, where stone can generally be obtained at less cost. Metal kerb protectors embedded in concrete laid *in situ*, as per Fig. 89, have been introduced in America. The web is perforated by large holes **A** to **B**, which prevent the concrete being divided into two easily fractured sections, above and below it.

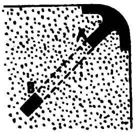


Fig. 89.

Fig. 90 shows a simple form of wrought-iron edging, which takes the place of a kerb. The plates are 6 in. to 10 in. deep by ½ in. thick, anchored by a tie rod to a mass of concrete at intervals of 4 or 5 ft. Joints in the edging are protected by a short inside coverplate of the same material.

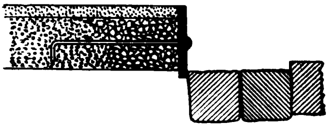


Fig. 90.

286. Wooden Kerbs.—Where kerbs of this description are adopted on the score of economy (and they have no other merits to commend them), they should be placed well above the invert, as in Fig. 92, to prevent the continual saturation of the wood.

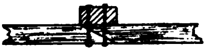


Fig. 91.

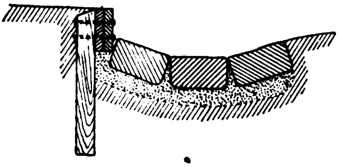


Fig. 92.

None but the most durable timbers, such as jarrah and red gum, should be used. The cost can be estimated on the basis of the prime cost of timber, plus an allowance of about 2s. per cubic ft. for laying, jointing, and fastening.

287. Tar Pavement.—The nature of this pavement is so well known that any description further than is given in the specification below is unnecessary. Tar pavements make cheap, but fairly satisfactory, footpaths for suburban streets and for country towns with limited incomes. They are not sufficiently durable in cities, where footways paved with this material cannot be regarded as better than makeshifts. To ensure a reasonable life of usefulness tar pavements should never be laid in cold or damp weather, and none but the best tar should be used. The materials are greatly improved if allowed to mature for a period of two or three weeks after tarring. By that time the stones will have absorbed all the tar they ever will, and any surplus will have drained off. Tar pavements should not be laid directly on undrained clay foundations, which are liable to swell and break up the paths. In such situations it is better to bed the pavement on a layer of gravel, sand, or finely-broken stone, well rolled before any tarred material is spread.

288. Example of Specification.—Tarpaving Footways:—

SPECIFICATION referred to in foregoing Form of Tender, Conditions of Tendering, General Conditions and Contract Agreement, and to be observed in the construction of tar-paved footways in the streets and roads of the Town of...................... as set out in the Schedule, as well as in any other streets or roads of that Town should the Council decide on extending the work of the Contract to such other streets or roads.

It is to be clearly understood that this is a Schedule of Rates Contract, and not a Contract for a lump or bulk sum. The quantities given in the Schedule are, as to the works actually scheduled, approximately correct, but the Council does not guarantee such quantities, and only the actual measured quantity of work done will be paid for, whether such quantity shall be more or less than the scheduled one, subject however to the scheduled quantity not being increased or diminished by more than [thirty] per cent., unless both the Council and the Contractor agree thereto as below.

Should the Council and the Contractor mutually agree to such a course, the Engineer may order the construction at scheduled rates of any other tar-paved footways in any situations or of any widths in the Town of..........................for a period of twelve months from ...., it being clearly understood that at the completion, including maintenance of the work first scheduled, or of any subsequent quantity of work ordered in writing by the Engineer, either party shall have the right to determine the Contract.

It is expected that about £............will be expended on tar-paved footways within the next twelve months, but the Council does not guarantee this.

General Description.—The works of this contract will comprise the construction, anywhere in the Town of........................., of tar-pavement, as specified below. The metal, screenings, dust, sand and coal tar used will be all of the best quality, the tar being free from light oil, water, or any other defect. When a length of pavement is undertaken it must be carried on smartly to completion, so as to cause as little inconvenience as may be to the general public.

Clearing.—Any roots or other obstructions on the ways to be paved must be removed, and any holes caused by their removal must be made up with sound filling, well rammed and consolidated.

Formation.—The paths or other sites for the tar path are to be neatly boxed out to the required widths, and to such transverse slopes as may be ordered to a depth of 3½ inches (three and a-half inches) below the finished footway level, the foundation being drained, rammed and rolled where necessary, so as to be thoroughly solid and even. Care must be taken not to injure pipes and culverts crossing the footways constructed. All stuff excavated will be removed by the Contractor and spread and trimmed where directed, within 20 chains of the site of the work, or used as filling to secure necessary grades, being thoroughly rammed as above.

Paving.—This work will be done in three courses as under:—The bottom course is to consist of the best sound bluestone [or other] metal, 1 inch to 2 inch gauge, screened clean and free from chips, small stuff, and dust, thoroughly tarred as described below, and evenly laid, so that when thoroughly rolled with a roller weighing not less than 70 lbs. per inch of width, it may finish fair and even and 2½ inches thick. Any portions of this, or any of the other courses, that cannot be properly reached by the roller must be well rammed with an approved iron rammer not less than 20 lbs. in weight. The intermediate course will be of bluestone [or other] screenings up to ¾-inch gauge, from which the fine stuff has been removed by means of a ¼-inch sieve, well tarred as below, and finishing true and even, and ¾-inch thick when well rolled and rammed as above.

The top course is to consist of a layer of fine screenings with the dust left in, generally known as toppings, tarred as below, and to finish after proper rolling and ramming ½-inch thick. The whole will be finished off with a light coat of bluestone dust and screenings passed through an ⅛-inch screen.

Tarring.—The metal for the bottom course will be thoroughly coated throughout with the best coal tar, which is to be warmed sufficiently to make it run readily, but not boiled.

The screenings for the intermediate course will be thoroughly coated with hot but not boiling tar.

The top course will also be thoroughly mixed with hot tar. All tarring must be done under cover within the Town of.................... so as to be easily inspected by the Engineer or his representative. All stone and screenings must be thoroughly dry before being tarred, a kiln being used if ordered. All surplus tar must be allowed to drain away before the stuff is used, but no material on which the tar has, in the opinion of the Engineer, become unduly dried, will be accepted. All the pavements must be laid during dry weather.

Maintenance.—[As per Wood Blocking Specification, § 248].

289. Cost and Durability of Tar Pavement.—The quantity of tar required is about as under:—

10 gallons per cubic yard of 1-in. to 2-in. metal, measured loose.
16 gallons per cubic yard of screenings, measured loose.
25 gallons per cubic yard of fine toppings, measured loose.

When tar can be obtained at 4d. per gallon the total cost of three-coat work, such as specified above, inclusive of boxing, ranges from 1s. 6d. per square yd. where large areas are laid to 2s., or sometimes a little over, for comparatively small lots. The life of tar pavements is variable, depending, of course, largely on the weight of traffic, but in average cases signs of decay are evident after eight to ten years, or even sooner if the traffic is heavy and the work is not well done in the first instance. Frequent patching is subsequently required, until finally resurfacing is necessary. Tar painting and dusting the surface every two years after a path is laid is about the only means of prolonging its usefulness. The comparatively short life possessed by tar pavements in general is due to the perishing or oxidation of the tar, which becomes brittle, and loses its binding properties.

290. Cement Matrix Pavements.—These are laid *in situ*, and also in the form of specially-prepared slabs or flags. The composition of each is very similar, and consists of broken stone screenings and Portland cement in the proportions of about 3 to 1, with a wearing surface of finer chips and cement in about 2 to 1. The total thickness is from 2 in. to 3 in., depending on the foundation, which is best of broken stone rolled to about 3 in.

Formerly concrete pavements were laid in continuous lengths, but were found to crack badly under changes of temperature. Modern practice requires that they be laid in panels or bays about 6 ft. wide, and divided by strips of wood, which are generally withdrawn before the concrete is set. The usual practice is to construct alternate bays, and to finish them off before the intermediate ones are commenced. The surface is trowelled smooth, but it is not advisable to polish it too highly, or it will be unduly slippery. When specially good foothold is required the surface can be indented with a spiked roller, giving a pit pattern with holes ⅛ in. x ⅛ in. at ½-in. centres. Traffic must be kept off the pavement for at least a week after laying. During this period it should be covered with sand or bags, and kept constantly moist. Very satisfactory pavements can be laid in this way, provided that the cement is of the best quality and the work is carefully carried out. The cost for 3-in. work in city streets, including excavation and preparation of the foundation, is about 5s. 6d., when carried out on a fairly extensive scale, up to 7s. 6d. per square yd. for small areas.

There are firms operating in Australasia who specialise in the laying of cement pavements, to which high-sounding names are assigned, and who employ proprietary processes in their execution. In some of these we have seen very badly-made joints, and the surfaces begin to fret away within a few months of their being laid down. We are of opinion that, where pavements of this class are concerned, the maintenance period should never be less than one year.

291. **Cement Matrix Flags.**—The advantages of flags lie in the facility with which they can be laid in the first instance, and removed and reset when required. They are made in a variety of lengths, ranging between 1¼ and 4 ft., but are generally 2 ft. wide. In thickness they run from 2 in. to 2½ in. Reinforcing bars are inserted where strength as a beam is required. In composition the flags are very similar to pavements laid *in situ*, washed granite chippings being preferred to any other stone.

The flags are shaped either in moulds or machine-pressed in a comparatively dry condition. Each method has its advocates, though machine compression is rather more favoured at present. The cost is slightly in excess of monolithic pavement, and varies between 6s. and 8s. per square yd., depending on the situation and extent of the work.

A recent development, and one that will concern us more closely when destructors become numerous, is the manufacture of concrete flags principally from the hardest of the refuse clinker. The practice in England is to crush the clinker to pea size, and mix it with cement in the proportions 1 to 3, and to provide a wearing face, about ¾ in. thick, with 1 part of cement to 3 of granite chippings. The whole is compacted to a total thickness of 2½ in. under hydraulic pressure, and the flags are allowed to mature for six months.

292. Brick Pavements.—For footways in towns brick pavements are not very popular. Their use should be confined to localities where picked machine-made bricks are obtainable at reasonable cost, and even then to the less important streets. For footpaths the bricks can be laid on their flats on sand bedding, with close joints, grouted in cement mortar. Hints on brick pavements suitable for roadways are given in §§ 262 to 266, which see. The authors have laid a great number of brick-on-flat pavements, costing, exclusive of sand bedding, as under:—

	s.	d.
Bricks at 55s. per 1000 delivered alongside path	2	6
Labour in light excavation, setting and grouting at 20s. per 1000	0	11
Cement and sand in grouting; each cask suffices for 65 square yards	0	3
Total cost per square yard	3	8

Brick-on-edge pavements would cost about 5s. per square yard.

The useful life of a good brick footway is at least twenty-five years, and though the first cost is about double that of tar pavement, the economy of the former is quite appreciable.

293. Natural Stone Flags.—Though extensively laid in former days in almost every one of our cities, the use of natural stone flags is being abandoned in favour of the newer pavements. The principal objections to flags are their high cost, the tendency towards uneven wear, and the fact that they become smooth and slippery. They possess the advantage, however, of being much more easily removed and replaced than the newer monolithic pavements. They can also be reversed when worn. The very best flags obtainable are imported from Caithness, in Scotland, but they are necessarily too costly in this country for footways. Basalt, sawn and squared, makes an excellent flag, and so does so-called trachyte from Bowral, near Sydney. The cost of 2-in. Malmsbury (Victoria) stone flags is about 10s. 6d. per square yard at the works. Trachyte flags sawn on one side cost 20s. per square yard in Sydney. Castlemaine (Victoria) slate 1½ in. thick costs about 8s. 3d. in Melbourne, while Sydney sandstone flags 4 in. thick cost 11s. 6d. to 12s. per square yard in that city. Flags should be laid on a sand or cinder bedding, but never directly on a clay foundation.

294. Asphaltum Paths.—In § 229, asphaltum products used on carriage ways were classified as under:—

(a) Natural rock compressed asphalt.
(b) Mastic asphalt.
(c) Trinidad asphalt.

Of these, the first mentioned, though largely used in street work, is rarely laid in footpaths, for the reason that it is too poor in bitumen to be worked by hand floats, and, being laid in thin layers, will not stand heavy ramming.

Mastic Asphalt consists, as explained in § 230, of naturally bituminous rock enriched by the addition of bitumen, most of which comes from Trinidad; clean grit is generally added at the same time. It is laid hot on a concrete foundation at least 2½ in. thick, but better 3 in., which must be thoroughly dry, or blistering will result, and worked with wooden floats to the required thickness of ⅝-in. to 1 in. The surface is finished with smoothing irons. (See Fig. 81.)

Trinidad Asphalt, much as described for the wearing coat in § 230a, and shown in Fig. 82, makes an excellent path when laid on a concrete base as above. The proportions of bitumen, grit, &c., are most carefully arranged by experts, under whose direction the work is laid. The thickness may be ⅝ in., but 1 in. is better for important footpaths.

295. Cost and General Considerations.—Asphaltum paths ⅝ in. thick when laid over extensive areas cost about 6s. 6d. per square yard in this country, exclusive of the concrete base, which can be laid for from 2s. 6d. to 3s. 3d. per square yard.

Asphaltum footpaths are superior to all others, and nothing but their cost, which is approximately 10s. per square yard, prevents their general adoption. They are smooth and jointless, while the facility with which portions can be taken up and replaced or repaired is greatly in their favour. Portions of the asphaltum that have become worn or blown can, by remelting, be made equal to new.

CHAPTER XV.

DRAINAGE.

296. The necessity for subsurface drainage in clayey soils or in swampy places has been discussed in Chapter V. on Earth Roads, in which appropriate types of drain have been discussed. The importance of close attention to this matter has been mentioned and the opinion expressed that far too little provision is usually made in such situations for the protection of the foundations of roads by the removal of underground water. Where the soil, however, is sandy or calcareous, or where the subsoil consists of fairly open gravel, under drains are seldom, if ever, required.

The volume of water to be contended with in surface drainage problems is not confined to that actually falling upon the road, but includes, in addition, that collected upon the catchment area above. In fact, the road engineer is more often than not called upon to provide for the safe passage of the general drainage of the district. In towns practically the whole of the roof water finds its way to the roads, from which it is the undoubted duty of municipalities to convey it to a safe outfall, such as some well-defined watercourse, without detriment to ratepayers. This obligation on councils has been clearly established in actions at law, and the difficulties are most pronounced in thickly-settled communities where the provision of underground storm-water sewers is frequently the only solution of a clearly difficult problem when funds are limited. It should not be necessary to remark that in carrying out all drainage works care should be taken to so grade the channels that they may not erode, with the effect of filling up watercourses and silting flat lands lower down. Instances have been met with in Victoria where drains have been constructed by public authorities with such enormous falls, up to 40 or 50 ft. per mile, through friable country, that scores of thousands of cubic yards of earth have been quickly scoured away, to the injury of the country down stream. In all cases the permissible velocity must not be exceeded, excess of fall being disposed of in properly-constructed drops or falls.

297. Drainage of Country Roads.—Obstruction or concentration of the natural flow of surface waters to the detriment of property situated either above or below road works is contrary to law. That is to say, municipalities whose works obstruct the natural flow, and raise the level of storm waters higher than they would otherwise be, are liable to be mulcted in damages by owners on the upper side of the road. Then, again, the collection of surface waters and the carrying of it by side drains to be discharged through culverts amounts to concentration which may damage lands on the lower sides of roads. In the construction of roads running transversely to the general fall of the country there is great danger of attack, and it behoves engineers to be particularly careful in the design of cross drainage works. Strictly speaking, road embankments of any sort in such situations are contrary to common law principles unless compensating provision is made for the safe delivery of concentrated or diverted flow to some outfall. In practice, however, it is impossible to avoid banking in road formation, and, by the liberal provision of culverts for cross drainage, damage to lands above roads can generally be avoided. Where the ground is particularly friable, and consequently subject to erosion by ever so little concentration if the country falls at all sharply, councils cannot in many instances escape penalties for damage done to land situated immediately below roads unless they are prepared to place culverts at exceedingly close intervals or alternatively to provide lined outfall drains on strips of ground over which rights are acquired for the purpose. The authors have successfully dealt with concentration difficulties in the manner illustrated by Fig. 93, on which the contours are shown by finely dotted lines. As will be seen, the road has a falling grade from **A** to **B**, where it crosses a gully and begins to rise towards **C**. In an actual case the road was first constructed so that all the water flowing naturally across the contours between **A** and **C** was collected at **B**, carrying with it large quantities of silt scoured from the upper watertables or ditches. There was no creek or watercourse receiving the discharge from **B**, the land a short distance below being a cultivable flat or hollow. The concentrated flow at **B** scoured out a channel for some 15 chains below that point; then, the grade flattening, the silt was deposited, covering crops and grass. To obviate this, culverts across the road formation were built at **A** and **D**, an open crossing being placed at **B**; rough dams were placed in watertable below **A** and **D**, and the water was carried across the road at **A**, **D**, and **B** into contoured ditches **AX**, **DE**, **BH**, and **BI**, whence it spilled down the hillside, much as if it had never been interrupted in its flow by the construction of the road. These contoured ditches were about of the cross section shown in the figure, the spoil bank being placed above the ditches and not made continuous. In this way natural conditions were practically restored and litigation avoided. In most similar cases we believe that such an arrangement is practicable, and if the road is designed with a view thereto in the first instance, the extra expense need not be heavy. The ditch spoil could be used in the formation, the culverts or open crossings could be small and pretty close together, so that the contoured ditches might be kept within the road reserve, or practically so.

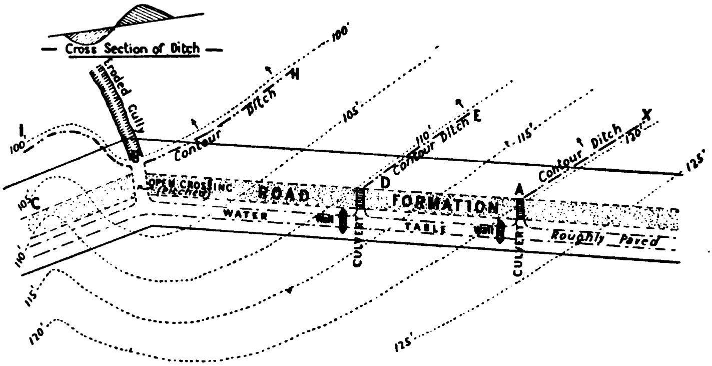


Fig. 93.
Showing how Natural Drainage Conditions can be Partially Restored.

298. **Watertable Drains.**—As it is manifestly unwise to permit storm waters to flow over road formations, unless they are specially prepared for such a contingency, on account of

the danger created by erosion and washouts, watertable drains are essential in almost every situation. In any case they are necessary to prevent waterlogging of the foundation in wet seasons. The general arrangement of watertables is indicated by the various cross sections to be found in this book. Where the volume of water to be dealt with is great, the dimensions must be increased by widening and deepening within practical limits, care being taken that dangerous excavations are not made for the purpose in close proximity to the driving track. On sidelong ground further catchwater drains are necessary to protect the slopes of cuttings from erosion, as mentioned in § 297. The discharging capacities of watertables, in common with drains of all sorts, are best calculated by the Chezy formula:—

$$\text{Discharge in cubic feet per second} = \text{area} \times c \times \sqrt{r} \times \sqrt{s}.$$

Values of "c" may be obtained by reference to "Trautwine," or one or two other books in common use. In the selection of the value for the coefficient of rugosity "n" it must be remembered that watertables on country roads soon become obstructed by weeds, grass, &c., and that .035 or even .040 is not excessive, though .025 can be adopted in channels kept free from such obstructions. The effective cross sectional area may generally be taken up to a horizontal line, say, 6 in. vertically below the crown of the road, provided both the watertable and the formation are graded with a satisfactory longitudinal fall to eliminate the possibility of spill over. In the plains it is not usual to take many levels for road formations, though sometimes it is a mistake to disregard them, as a slight rise invisible to the eye may not only spoil the discharging capacity of the watertables, but lead to unnecessary saturation of the road bed after rains. Excessive fall in road ditches is as undesirable as too flat a gradient, since erosion in one length invariably leads to siltation lower down. The maximum gradient allowable depends so much upon the nature of the soil that general rules cannot be given; it may be mentioned, however, that in coarse sandy loam there is less danger of erosion than in many clayey soils, classed as "sugary," which readily melt down in water. Unless the watertable is very long, and carries a large body of water, slopes of 1 in 100 will rarely lead to objectionable scour, while gradients of 1 in 20 will stand in other places. When scour is feared it is always advisable to encourage the growth of binding grasses, and it is a mistake to scrape or chip the watertables merely for the sake of appearances. Where protective works are necessary it will often suffice to construct rough drop walls sufficiently close together with rough aprons below them as being much cheaper than continuous paving. The upstream face of each wall is stanched with earth and gravel, and the apron below it is kept down below the ordinary grade of ditch as excavated. The result is that the watertable bones itself out into a series of grades of moderate fall from the aprons to the crests of the walls next below them. Occasionally it may be necessary to construct an additional intermediate wall here and there, but even so, this plan is much cheaper and quite as effective as the rough paving of the whole of the watertable, provided that the slope is not so great as to necessitate an undue number of such walls. In hard rock a steep grade is immaterial so long as the water carried along by the watertable drains does not overflow to such an extent as to wash away the formation. The remedy is to prevent the accumulation of too great a volume by the insertion of cross drainage works at sufficiently frequent intervals.

299. **Run-off from Storms.**—For the satisfactory design of road drains and cross-drainage works, an estimate of the volume of water to be coped with is very necessary. It is true that in many cases the practical engineer can determine the necessary dimensions for culverts and watertables without special investigation. In more important works rough and ready estimation does not suffice, and may lead to inefficiency or wasteful expenditure. What concerns the designer most is the maximum run-off to be expected after severe storms. If the structures are important and on main lines of communication, where interruption to traffic would be serious, the very heaviest storms must be provided for. If, on the other hand, structures or the roads are not of sufficient importance to warrant increased expenditure to meet remote contingencies, it may be good policy to design the bridges and culverts for rains of such intensity as might be expected to occur once

in, say, fifteen years, and to risk the consequences of a deluge that might not come once in half a century. For the estimation of flood discharge many formulae have been devised, but their application is of doubtful reliability unless the conditions on which they were based are well understood. For instance, formulae such as Dickens' or Ryves', based on Indian experience, are inapplicable to temperate zones. Prof. Kernot's formula for bridge and culvert openings is compiled to meet Australian conditions, and is useful as a check on more detailed estimations :—

Area of waterway in sq. feet = c (area of catchment in sq. miles)$^{\frac{3}{4}}$
where c = 40 in average cases of ordinary rainfall,
= 30 in flat absorbent areas,
= 80 in hard rocky or town areas.

It will be noted that in this formula no account is taken of the fall of the stream or the permissible afflux at the bridge or culvert. For example, an 18-in. pipe culvert through a road embankment on a hillside might discharge as much as a 4-ft. culvert in flat country. The maximum discharge previously recorded in streams may sometimes be obtained from gaugings, but it is never certain that the maximum has been observed. Further, if conditions, such as the percentage of hard surfaces governing run-off, are subject to change, the maximum recorded stream flow of the past is no safe guide for the future. Clearing of scrub, making of roads, and general improvements, as well as the trampling and consolidation of ground by stock, tend to increase the run-off, and render perennial streams more or less torrential in character. Extensive cultivation, on the other hand, has the effect of diminishing the discharge. The accepted method of estimating flood flow is fully explained by Mr. Chamier, of Sydney,* and as applied to moderate-sized catchment areas such as may be expected in road problems, is, briefly stated, as under :—

After rain commences to fall the volume of water discharged at the outlet, or point at which the estimation is desired, increases until water from all portions of the catchment are arriving *simultaneously* at this point. Assume, therefore, that the rainfall is general over the catchment area, and that the fall is of sufficient duration to permit of the flood waters from every part of the area reaching the outlet at the same moment. Then proceed to estimate the length of time that will be taken for water from the furthermost extremities of the catchment, following as it must the sinuosities of the gullies, to reach the outlet, basing calculations on the slope of the ground and the nature of the watercourses. In a creek or well-defined watercourse flood waters will advance at velocities ranging from 2 to 4 miles per hour, but over heavily-grassed or scrubby ground without any definite channel the rate may not exceed half a mile per hour, though one mile per hour may be allowed if the slopes are steep. Where defined channels are available approximate velocities may be calculated by Kutter's formula. The best test of all, however, is to ascertain during heavy rains the interval of time that elapses between the commencement of the fall and the period of highest water. In a long narrow catchment area it may happen that in storms of moderate duration water in considerable volume cannot, at certain points, arrive simultaneously from all parts of the catchment above those points. For instance, in a heavy storm of half an hour's duration the flood waters from the nearer areas may have all passed such points before the waters from the head of the catchment have time to reach them. In making calculations for run-off this consideration must not be lost sight of.

---

* Min. of Proc. Inst. C.E., Vol. CXXXIV.

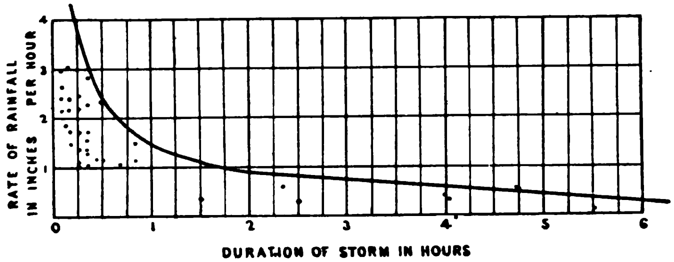


Fig. 94.

Curve of Rainstorm Intensities at Melbourne.

Having estimated the interval by one or other of the methods indicated, the next step is to consider the maximum rate of rainfall that might reasonably be expected for the same period, remembering that the shorter the duration the heavier the rate of precipitation. Intensity of rainfall varies with the local conditions, and the probabilities can only be ascertained with reasonable precision from observations extending over a number of years, and from which a diagram showing the maximum recorded intensities of storms can be compiled. Fig. 94 shows such a curve for storms of comparatively short duration as recorded in Melbourne. Though the results are applicable to one district only, the diagram shows the method with sufficient clearness.

Of the rainfall only a proportion runs off immediately; some is evaporated, some is absorbed by the soil, and some is ponded in lagoons, gutters, roads, &c. The percentage discharged within the duration of a storm ranges from 30 per cent. to 80 per cent. Mr. Chamier gives the following as a rough guide:—

Flat country, sandy soil or cultivated land	25 to 30 %
Meadows and gentle declivities, absorbent land ..	35 to 45 %
Wooded hill slopes and compact or stony ground ..	45 to 55 %
Mountainous and rocky country or non-absorbent surfaces	55 to 65 %
Naked unfissured mountains, very steep ground, or paved streets	80 %

It has been proved by experience that, except for very small basins, flood volumes are inversely proportional to the areas of the catchments. The ratio of decrease is not accurately known, but may be taken as the fourth root of the area cubed. For areas under one square mile the maximum flood discharge may then be calculated by the following formula, it being remembered that 1 in. of rain per hour gives nearly enough a discharge of 1 c.f. per second per acre if all the water runs off.

Discharge in c. ft. per sec. $= \mathbf{A} \times \mathbf{R} \times \mathbf{C}$

where $\mathbf{A}$ = area of catchment in acres,

$\mathbf{R}$ = rate of greatest anticipated rainfall in inches per hour,

$\mathbf{C}$ = proportion of rainfall expected to be discharged.

For areas exceeding one square mile:—

Discharge in c.f.s. $= 640 \times \mathbf{R} \times \mathbf{C} \times \mathbf{M}^{\frac{3}{4}}$

where $\mathbf{M}$ = area of catchment in square miles.

Example.—Compute the probable maximum discharge from an area of 500 acres of fairly steep ground from which 50 per cent. of the rainfall may be expected to run off. The inclination and nature of the valley is such that waters from the head of the catchment would probably reach the outfall half an hour after the rain commenced to fall.

For a storm of thirty minutes' duration assume that in the district under discussion rain at the rate of 3 in. per hour may be expected.

$$\text{Discharge} = 500 \times 3 \times .5$$
$$= 750 \text{ c.f.s.}$$

300. **Flow in Pipes.**—The discharge of pipes over 4 in. diameter is best calculated by the Chezy formula with Kutter's value of c.

$$\text{Discharge in c.f.s.} = AC\sqrt{r} \times \sqrt{s}.$$

n = .010 for very smooth iron pipes, and for pipes with a highly-smoothed cement surface.

= .011 for smooth iron pipes and for pipes or sewers rendered with 1 to 3 cement mortar smoothly finished.

= .013 for slightly-incrusted iron pipes and for well-laid brick sewers.

= .015 for moderately-incrusted iron pipes and for ordinary brick sewers.

.017 for heavily-incrusted pipes and for rubble masonry in cement.

TABLE XVIII.

For Calculating the Discharge of Pipes and Circular Sewers.

Diam. in inches.	Value of AC $\sqrt{r}$ where n equals—					Fall in Feet per Mile.	$\sqrt{s}$
	.010	.011	.013	.015	.017		
5	4.1	3.6	2.9	2.4	2.0	6	.0337
6	6.9	6.1	4.8	4.0	3.3	8	.0389
7	10.6	9.3	7.4	6.1	5.2	10	.0435
8	15.4	13.5	10.8	8.9	7.5	15	.0533
9	21.2	18.7	15.0	12.4	10.5	20	.0615
10	28.3	25.0	20.1	16.6	14.1	25	.0688
11	36.9	32.6	26.3	21.8	18.5	30	.0754
12	46.9	41.5	33.5	27.8	23.6	35	.0814
14	71.3	63.2	51.2	42.6	36.2	40	.0870
16	102.5	91.0	73.8	61.7	52.6	50	.0973
18	141.2	125.6	102.1	85.5	73.0	60	.1066
21	214.1	190.8	155.7	130.6	111.8	70	.1151
24	307.6	274.5	224.6	188.8	164	80	.1231
30	560	501	411	347	299	90	.1305
36	912	817	674	571	493	100	.1377
42	1375	1234	1021	867	751	120	.1508
48	1963	1764	1464	1245	1081	160	.1741
54	2682	2413	2007	1711	1487	220	.2041
60	3543	3192	2659	2273	1977	264	.2236
72	5731	5176	4322	3702	3232	330	.25

Example.—Compute the discharging capacity of a long pipe 24 in. diameter, with a hydraulic gradient of 30 ft. per mile n = .011. Entry and velocity heads to be ignored.

$$\begin{aligned} \text{Discharge} &= AC\sqrt{r} \times \sqrt{s}. \\ &= 274.5 \times .0754. \quad \text{(See Table XVIII.)} \\ &= 20.7 \text{ c.f.s.} \end{aligned}$$

301. Pipe Culverts.—Where a limited waterway suffices pipe culverts are the most convenient, and are generally adopted when materials are obtainable at reasonable cost. The pipes may be of stoneware, cement, reinforced concrete, iron or steel. Culverts of the three first-mentioned materials have an almost unlimited life if properly protected from traffic. Cast iron and wrought iron are perfectly satisfactory if properly coated, but are expensive. Spirally-riveted steel pipes are much used, and, while very strong, are reasonably cheap and easily transported.

Market sizes and approximate costs at Melbourne of vitrified stoneware pipes of good quality are given in Table XIX., together with cost of excavation, laying, and jointing, but not inclusive of railway freight or cartage beyond five miles. The prices, of course, vary a good deal, and occasionally fall much lower than stated in table.

TABLE XIX.

VITRIFIED STONEWARE PIPES.

Internal Diameter.	Approximate Weight per Foot in Lbs.	Cost of Pipe per Foot.	Excavation and Re-filling, allowing 2 Feet of Cover at 2s. per Cub. Yard.	Laying and Jointing per Foot.	Total Cost per Foot, Laid and Jointed.
4"	12½	3d.	4½d.	1d.	8½d.
6"	19	4¾d.	4½d.	1¼d.	10½d.
9"	30	8d.	5d.	1½d.	1s. 2½d.
12"	40	1s. 4d.	5½d.	2½d.	2s.
15"	55	2s.	6½d.	4½d.	2s. 11d.
18"	80	3s.	7½d.	8d.	4s. 3½d.
24"	140	11s. 6d.	9d.	1s. 4d.	13s. 7d.

The general arrangement of pipe culverts is to lay the pipes between brick or masonry, or sometimes timber, face

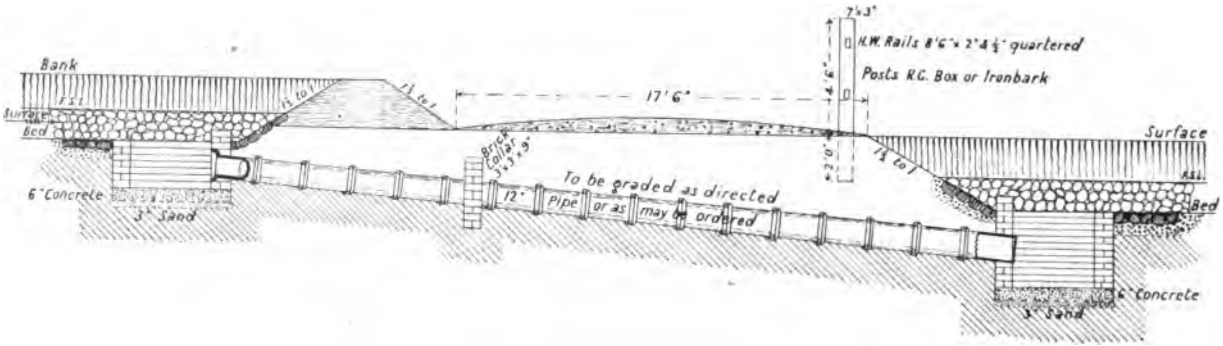
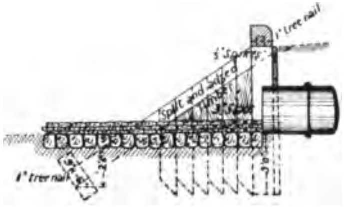


Fig. 95.
Pipe Siphon utilised as Drop and Crossing.



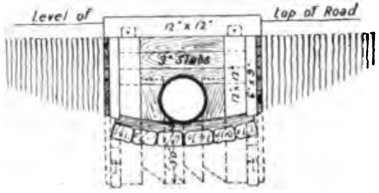


Fig. 96.
Fig. 97.
Timber Head for Drain Pipe.

walls for the protection of the pipes, and to provide rough paving to prevent erosion at both the inlet and outlet ends. The pipes should be laid with a slope in the direction of flow, and the cover should be at least 18 in. at the centre, unless an iron pipe is used, when as little as 9 in. is sufficient for ordinary traffic, if the road is macadamised. Fig. 95 shows a type of pipe siphon, utilised also as a drop, adopted by the authors for the passage of drainage or irrigation waters under roads. Siphons of this type are recommended where sufficient cover cannot otherwise be obtained, but their use should be avoided if sewage-polluted waters are to be conveyed.

Figs. 96 and 97 show an effective design for timber heads to pipe drains adopted by the New South Wales Government.

302. Discharging Capacity of Pipe Culverts.—Calculations to ascertain the discharging capacity of pipe culverts and siphons which are classed as "short" pipes are best explained by working the following actual case.

Example.—It is proposed to discharge 25 c.f.s. through a circular pipe culvert 24 in. diameter of extra smooth face, and 80 ft. long, provided that the difference in water level above and below the road embankment does not exceed 1 ft. 6 in. The water approaches the culvert in a drain leading directly to the pipe head at a velocity of 3 ft. per second. The area of the pipe is 3.14 sq. ft., and the velocity through it $= \frac{25}{3.14}$, say, 8 ft. per second.

The *velocity head* required to generate a velocity of 8 ft. per second calculated by the formula $h = \frac{v^2}{2g} = \frac{8 \times 8}{64.4}$ = practically 1.00 ft. The water approaches at a velocity of 3 ft. per second, which, working by the same formula, gives a velocity of .14 ft. The head required to generate the increased velocity is then $1.00 - .14 = .86$ ft.

Entry head, or the head required to overcome the obstructions to flow at entry, may be taken at one-half the velocity head, or .43 ft.

The head required to overcome *friction* in the 80 ft. of pipe can be calculated by Kutter's formula, using Table XVIII. n = .010 in this instance.

$$\text{Discharge in c.f.s.} = \mathbf{A} \times \mathbf{C} \times \sqrt{\mathbf{r}} \times \sqrt{\mathbf{s}}.$$

$$\therefore \quad \sqrt{s} = \frac{\text{Discharge in c.f.s.}}{\mathbf{A} \times \mathbf{c} \times \sqrt{\mathbf{r}}}$$

$$= \frac{25}{3.14 \times 139 \times .71}$$

$= .0807$ corresponding to a grade of about 35′ per mile, which in 80 ft. is only about .06 ft.

The total head, or difference in level between the head and tail water, is then .86 + .43 + .06 = 1.35 ft., say 1 ft. 4 in. It will be noted that in short pipes the head is almost wholly due to velocity and entry, that required to overcome friction being trifling.

303. Afflux at Bridges and Culverts.—When the waterway of a stream is contracted, the water becomes heaped up on the upper side until the head is sufficient to generate the increased velocity required to drive the whole discharge through the contracted area. The heading must not be such as to cause damage. The afflux may be approximated with sufficient precision for ordinary purposes by the formula:—

$$\text{Afflux in feet} = \left(\frac{v^2}{2g} - \frac{v_1^2}{2g}\right) + 20\,\%,$$

where v = mean velocity through obstruction in ft. per sec.
v_1 = mean velocity in unobstructed stream in ft. per sec.
g = 32.2.

Expressed in words, afflux is approximately equal to the difference between the heads required to generate the respective velocities in the obstructed and unobstructed portions of the stream, plus an allowance for the resistances due to eddies caused by square-edged entry, &c. With pipes the loss at entry is taken at 50 per cent. of velocity head. For bridges allow 15 per cent. to 35 per cent.; in ordinary cases 20 per cent. is safe, but if the entry is a bad one increase to 35 per cent.

Example.—A stream with a waterway of 1000 sq. ft., and mean velocity 5 ft. per second, is suddenly contracted to 700 sq. ft. at a bridge opening. Compute the approximate afflux. The velocity through the contracted area will be:—

$$\text{As } 700 : 1000 :: 5 : 7.14,$$
$$\text{so that } v = 7.14, \text{ and } v_1 = 5.$$
$$\text{Afflux} = \left(\frac{7.14 \times 7.14}{64.4} - \frac{5 \times 5}{64.4}\right) + 20\,\%.$$
$$= .48 \text{ feet, say 6 inches.}$$

The importance of arranging the wings so as to guide the water directly into the culvert, and not on to flat faces on each side of the opening that will cause eddies and interference with flow, and consequently greater afflux, must never be forgotten.

304. **Brick Sewers.**—These are usually constructed either circular or egg-shaped in section. For diameters up to 3 ft., 4½ in. brick ring is sufficient when the filling above does not exceed 7 or 8 ft., or where the cover is slight and heavy loads do not traverse the sewer. In situations where vehicular traffic cannot cross, 4½ in. work is allowable up to about 3 ft. 6 in. or 3 ft. 9 in. Where the haunches of the arch are well backed with concrete that thickness will be safe with a 3 ft. diameter sewer under 20 ft. of filling, provided that the foundation is sound.

The egg-shaped section possesses an advantage in that small flows are better taken care of in the narrower invert. The height is, in accordance with usual practice, one and a-half times the transverse diameter. Information concerning the design and erection of brick and concrete sewers can be obtained from text-books on the subject.

305. **Reinforced Concrete Pipes.**—Cylindrical and oviform pipes of the Monier type are now manufactured and stocked in several of our principal towns, and are very useful for certain works on account both of their portability and their great strength. They are, moreover, made in much larger sizes than vitrified stoneware pipes, are more easily laid

than brick sewers, and cost less where bricks are expensive. Circular pipes are stocked in diameters ranging between 9 in., with barrel averaging 1 in. in thickness, and 6 ft., 3¼ in. thick. The pipes can be manufactured in any required lengths up to 5 ft., and to any cross section that may be ordered. In Sydney they are stocked in 3 ft. 7 in. lengths; in Melbourne 4 ft. lengths. The larger diameters are best constructed in place without joints. Dimensions, weights and prices are obtainable from the manufacturers, who allow the pipes to mature for three to four weeks before delivery. One advantage possessed by these pipes, which are made without sockets, is the freedom from loss by breakages in transport, so common in stoneware. Oviform Monier pipes suitable for sewers, and elliptical pipes suitable, where the cover is limited for culverts, if placed with their shorter axes vertical, are manufactured in sizes ranging from 1 ft. 9 in. x 1 ft. 4 in. to 3 ft. 6 in. x 2 ft. 4 in., or to such other dimensions as may be required. Complete culverts can be constructed with Monier pipes by the provision of fronts, such as shown in Fig. 98, each made in one piece with coping, sloping wings and apron. These fronts are obtainable from the Reinforced Concrete and Monier Pipe Construction Co., of Melbourne, in most sizes, and make a very satisfactory job that can be carried out by unskilled labour. The joints are made either with a simple butt joint covered externally with 2½ to 1 cement mortar, reinforced by a wire netting bandage, or by a dovetail joint within the thickness of the barrel, which is filled with cement and pointed up. The dovetail joint is preferred in diameters 1 ft. 9 in. and over.

When calculating the discharging capacity of concrete pipes of this description, it is usual to allow a value of .010 for the value of n; with the very best brickwork. .013 must be taken, and even .015 in ordinary brick sewers. When comparing the relative costs of pipes in the two materials the hydraulic efficiency of each must not be lost sight of, since with the smoother material a smaller diameter will suffice.

306. Masonry Culverts and small span bridges of arched section are seldom built nowadays except on very important

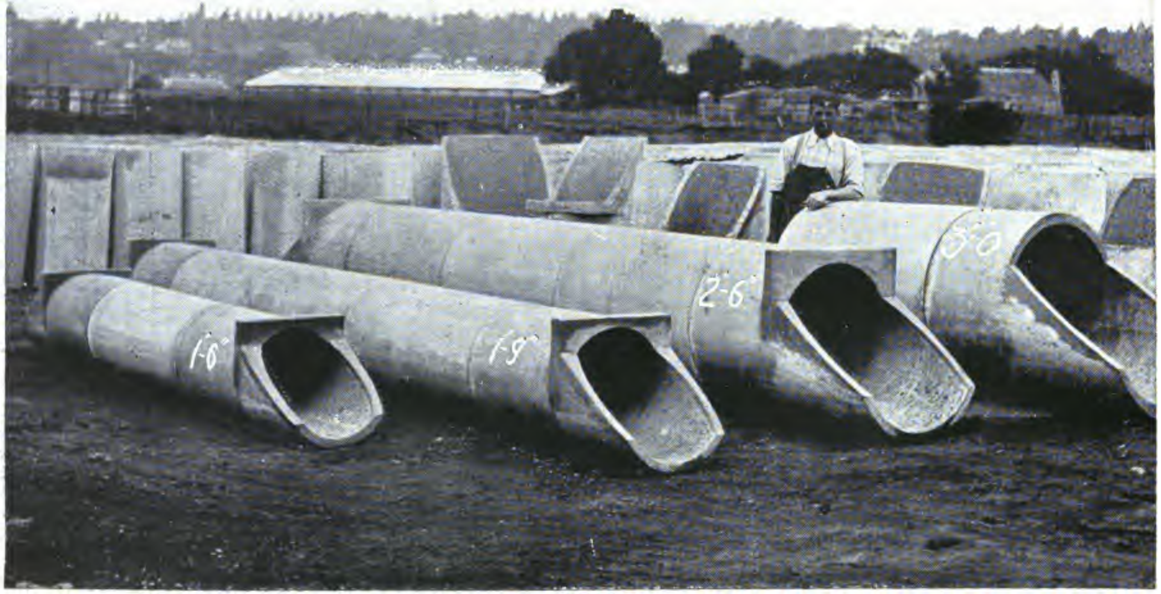


Fig. 98.—Monier Portable Culverts.

To face p. 284.

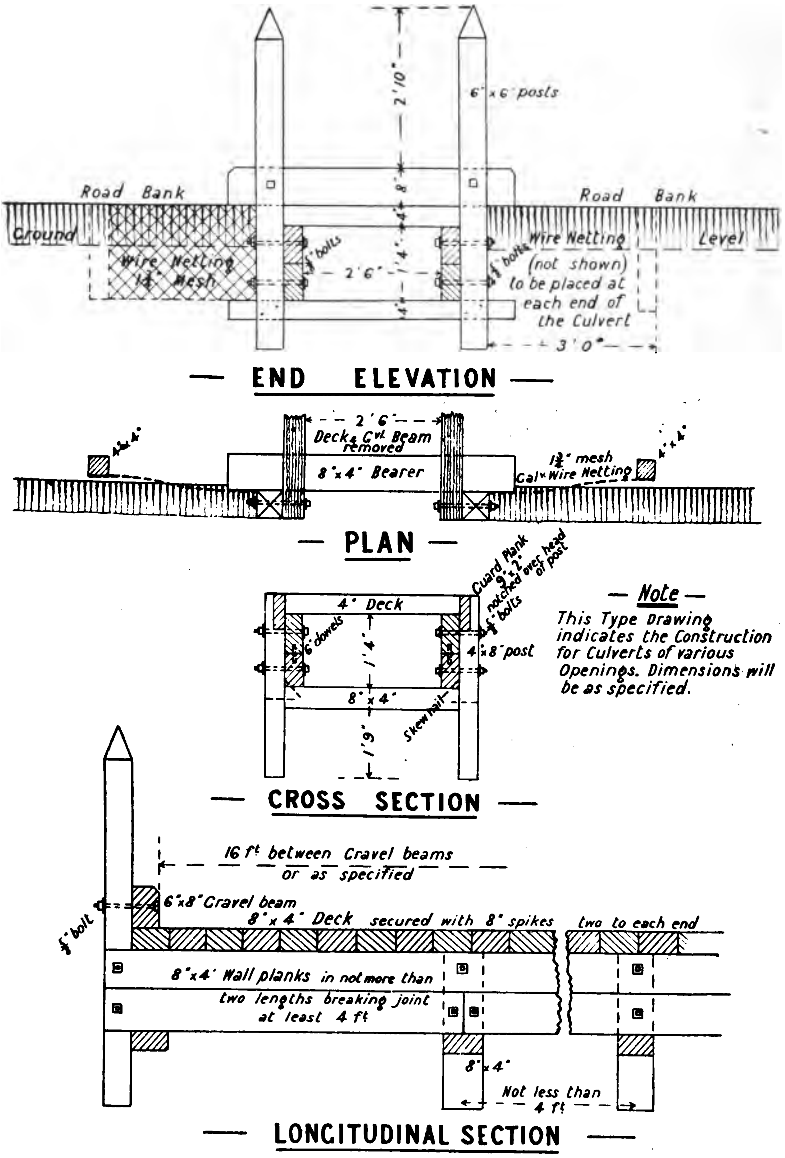

2'10"
6" x 6" posts
Road Bank
Ground
Wire Netting 1½" Mesh
½" bolts
2'6"
8"
4"
1'4"
4"
Wire Netting (not shown) to be placed at each end of the Culvert
Road Bank
Level
3'0"
— END ELEVATION —
2'6"
Deck & Crvl. Beam removed
8" x 4" Bearer
4" x 4"
1½" mesh Calv. Wire Netting
4" x 4"
— PLAN —
Guard Plank 9" x 2" notched over head of post
½" bolts
— Note —
This Type Drawing indicates the Construction for Culverts of various Openings. Dimensions will be as specified.
4" Deck
6" dowels
1'4"
4" x 8" post
8" x 4"
1'9"
Skew nail
— CROSS SECTION —
16 ft between Cravel beams or as specified
6" x 8" Cravel beam
8" x 4" Deck secured with 8" spikes two to each end
½" bolt
8" x 4" Wall planks in not more than two lengths breaking joint at least 4 ft
8" x 4"
Not less than 4 ft
— LONGITUDINAL SECTION —

Fig. 100.

Type Drawing of 2 ft. 6 in. Opening Culvert of Sawn Timber.

roads, and then only when rock can be obtained at very cheap rates, reinforced concrete having largely replaced rubble and cut stone work. A form of construction very suitable for small culverts consists of brick or stone abutment walls covered by a deck of reinforced concrete slabs in place of timber. For clear spans up to about 10 ft., flat portable slabs can be obtained in any desired shape. The larger sizes are, however, best built in place in timber forms constructed for the purpose. The thicknesses vary from 2 in. to 8 in. with the class of traffic and the available cover. For light traffic the dimensions average about as under when the filling is not less than 12 in. in depth.

Clear span	...	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.
Thickness	...	3 in.	4 in.	4¾ in.	5½ in.	6 in.	6½ in.

With lighter or heavier traffic and varying proportions of reinforcement the dimensions vary; they should in every case be proportioned by calculation. Fig. 99 shows the covering with reinforced concrete of the Reilly-street drain, Fitzroy, Victoria, where the clear span varies from 15 ft. to 17 ft. 6 in.

307. **Timber Culverts.**—Type drawings of a 2 ft. 6 in. opening timber culvert, a size that is commonly inserted in road formations, and sufficiently strong to carry traction engine traffic, are given in Fig. 100.

A light crossing for watertables or ditches is shown in elevation, Fig. 101. It will be noted that hand rails are omitted, and that the gravel beams are kept small to allow of the passage over them of farm implements. In agricultural districts the total width of the bridge should not be less than 12 ft., for which four beams spaced 4 ft. apart are required.

Typical cross sections of round and hewn timber culverts suited for country roads where suitable timber is available are illustrated in Figs. 102 to 104.

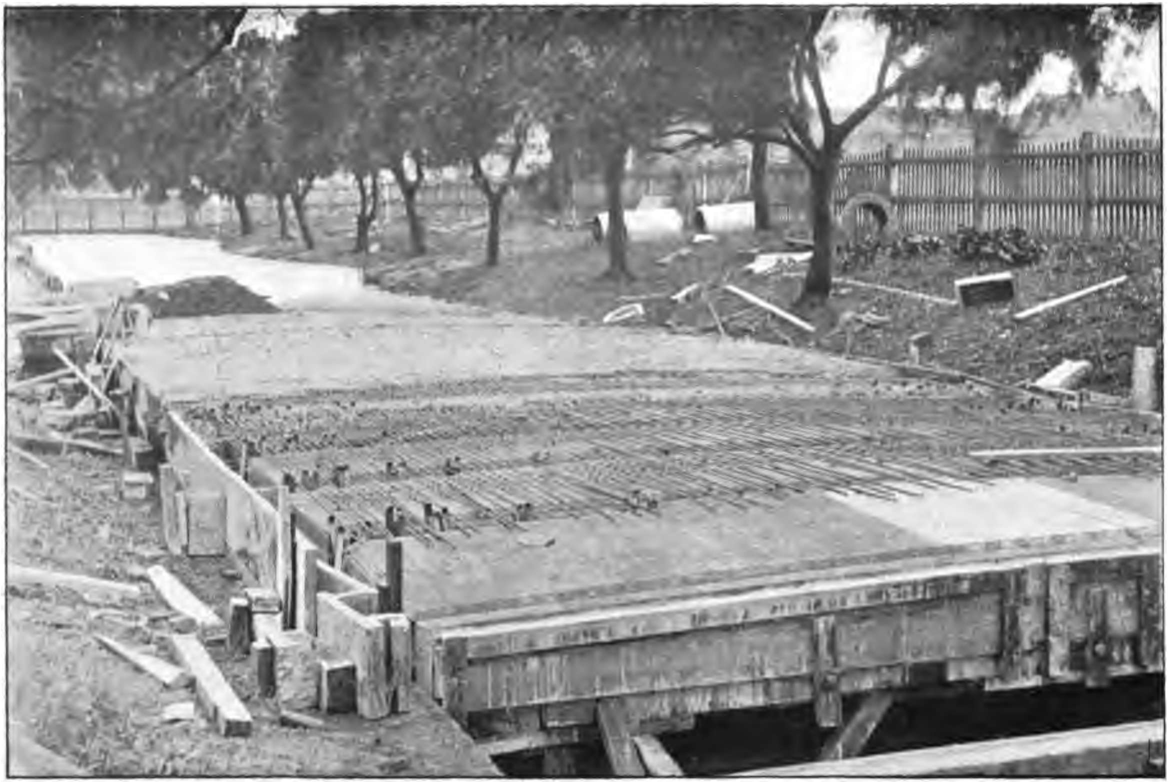


Fig. 99 —Reinforced Concrete Cover of the Reilly-street Drain, Victoria.

To face p. 286.

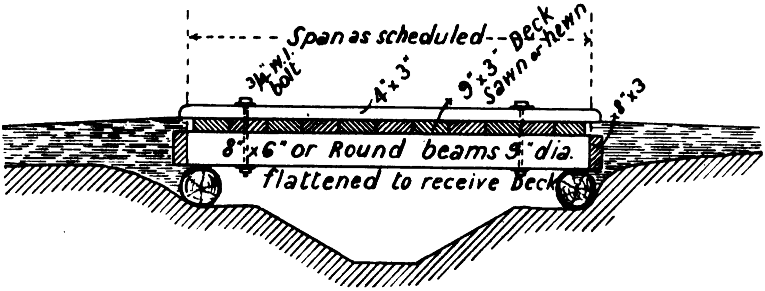
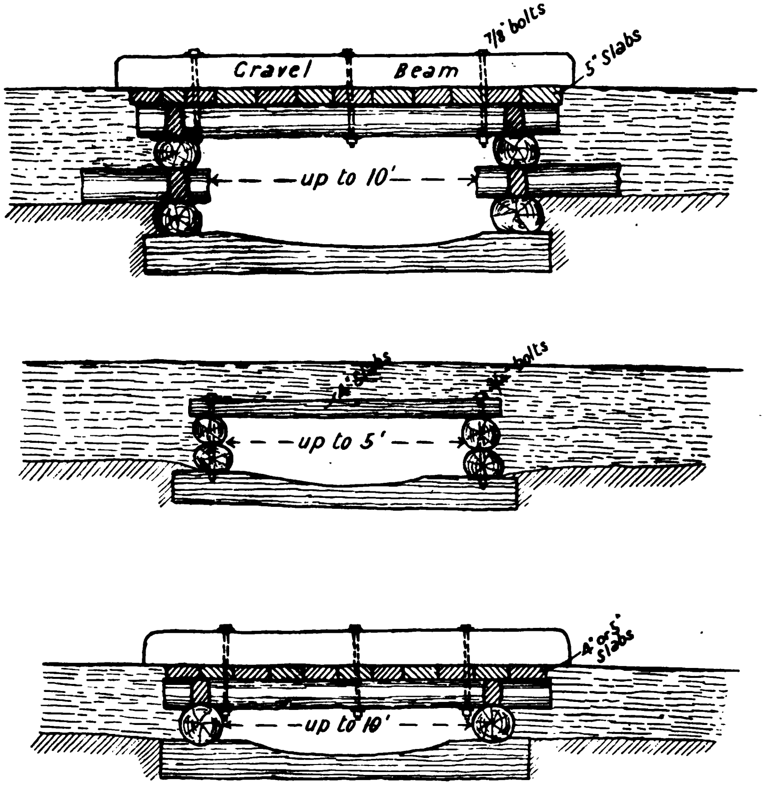
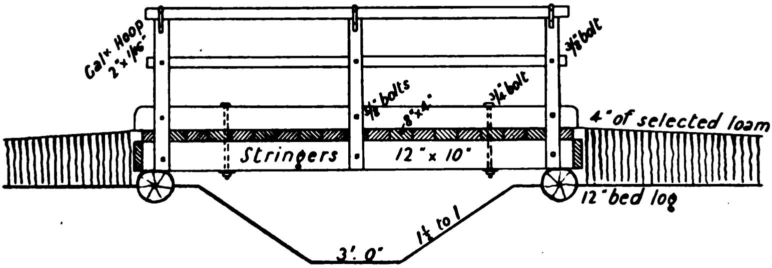


Fig. 101.
Crossing for Small Channels.

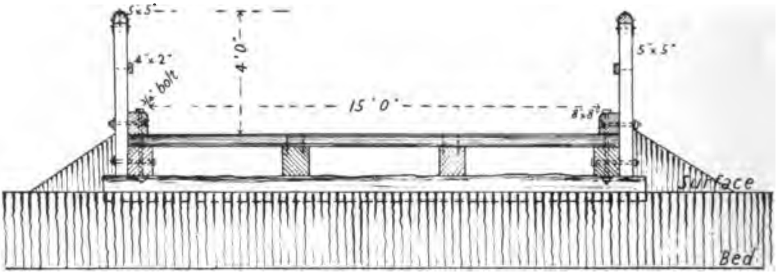


Figs. 102 to 104.
Cross Sections of Round and Hewn Timber Culverts for Country Roads.

Figs. 105 and 106 show a small road bridge designed to carry traction engine traffic where sawn timber is used, and where driven piles are not required.



— ELEVATION —



— CROSS SECTION —

Figs. 105 and 106.

Small Road Bridge in Timber.

In Fig. 107, showing a 12-ft. opening culvert, it will be seen that tongued-and-grooved planking is adopted for the abutment and wing sheeting. The grooves are made with a saw-cut 1⅛ in. deep, and about ⅛ in. broad, on the edge of each plank, and the tongues of galvanised iron hoop 2 in. x 1-16 in., lapped not less than 3 in. at joints.

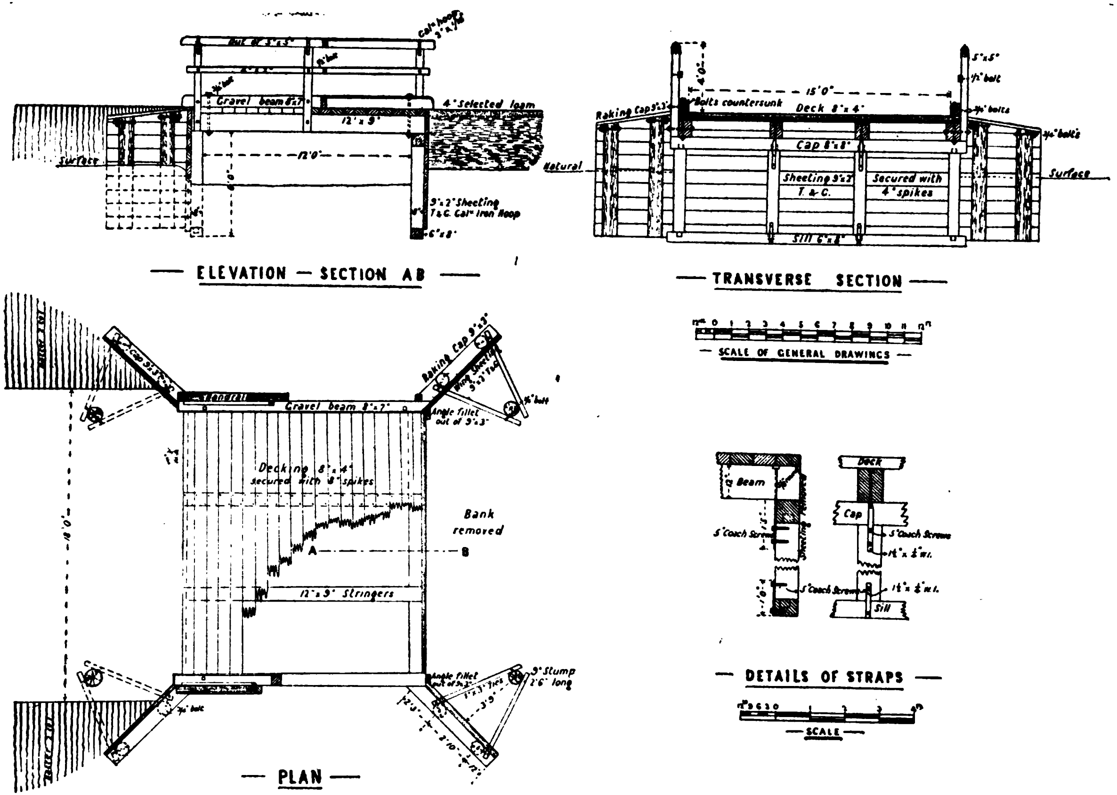


Fig. 107.—Timber Culvert, 12-ft. Opening.

Fig. 108 gives an alternative design for wings in round and hewn timber that has been largely adopted in New South Wales.

308. Steel Rail Stringers.—Flat-footed steel rails have been effectually employed as beams, laid on brick or stone side walls, with the heads down, each end of each rail being firmly bedded on a stone or brick, but not on a joint. Timber decking is laid on the upturned flanges, and the planks are secured by spikes of suitable lengths driven through bored holes and clenched under the flanges. In cases where timber-covered culverts carry foul water, the decking can be grooved and fitted with galvanised hoop iron tongues, described in the last paragraph, to prevent dirt from falling through.

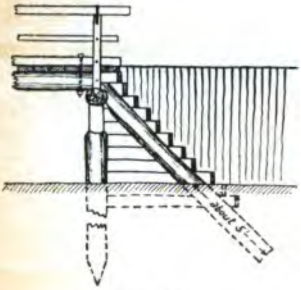


Fig. 108.

Wing for Culvert in Round and Hewn Timber.

309. Highway Bridges.—Fig. 109 shows a typical Victorian bridge with a span of 48 ft., and designed by Mr. W. M. Pullar, M.C.E., Melb., the cost being £201 at a time when contracts were being taken very low.

Fig. 110 shows a highway bridge over the Leycester Creek at Lismore, New South Wales. It consists of two composite truss spans of 104 ft. 9 in. each, one approach span of 33 ft., and two of 26 ft. The roadway on truss spans is 20 ft. between kerbs, while footways 5 ft. wide are provided on each side of the bridge. This bridge was designed by the Public Works Department of New South Wales, and erected under their supervision, at a total cost of about £5000, the work being completed in February, 1908.

Fig. 111 shows a brick highway bridge of two spans of 60 ft. each erected over the Merri Creek at Northcote, Victoria. This bridge was built to the designs of Mr. T. E. Rawlinson, C.E.

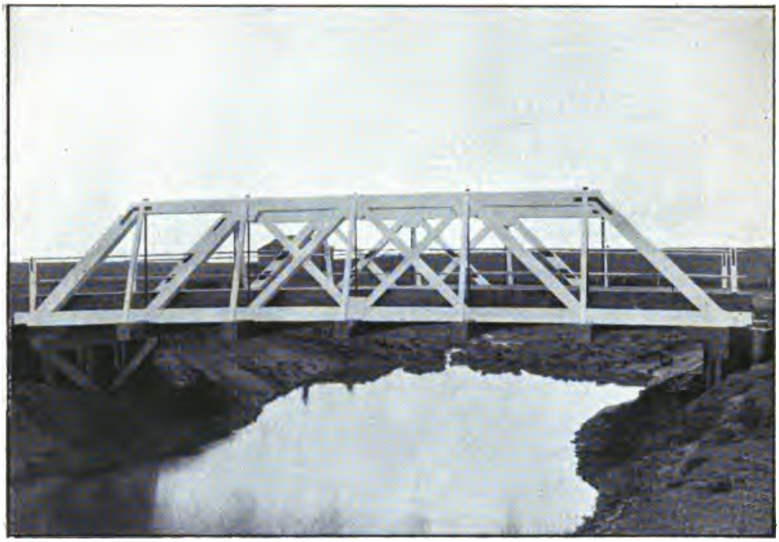


Fig. 109.
Typical Short-span Timber Bridge.
Photograph lent by Professor Kernot.

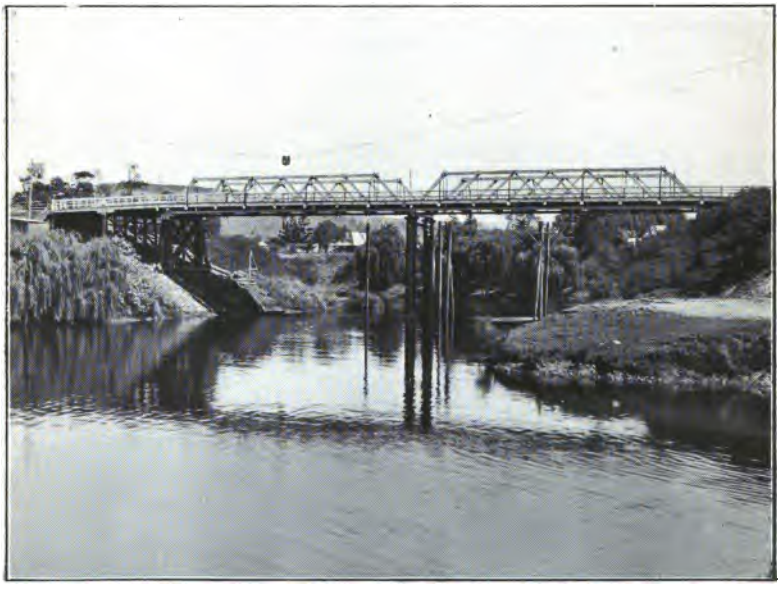


Fig. 110.
Example of a New South Wales Highway Bridge.

To face p. 290.

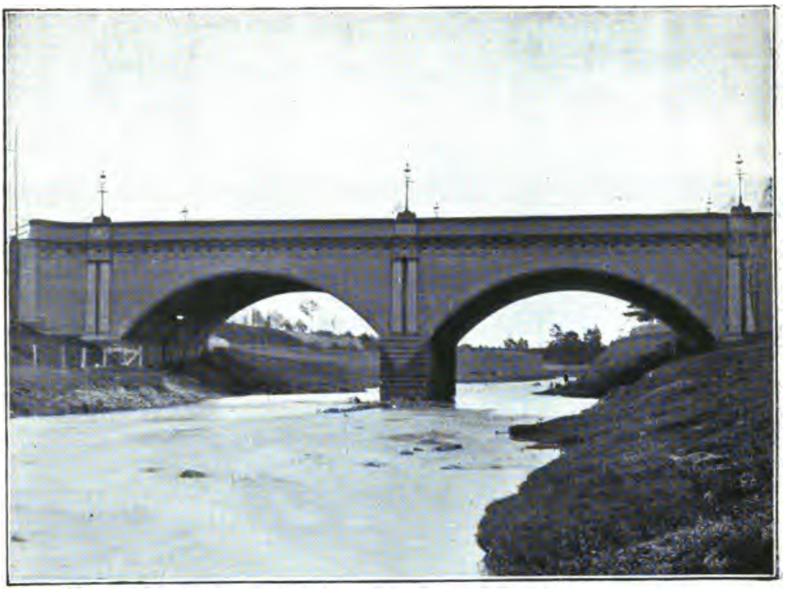


Fig. 111.

Example of a Highway Bridge in Brick.

Photograph lent by Professor Kernot.

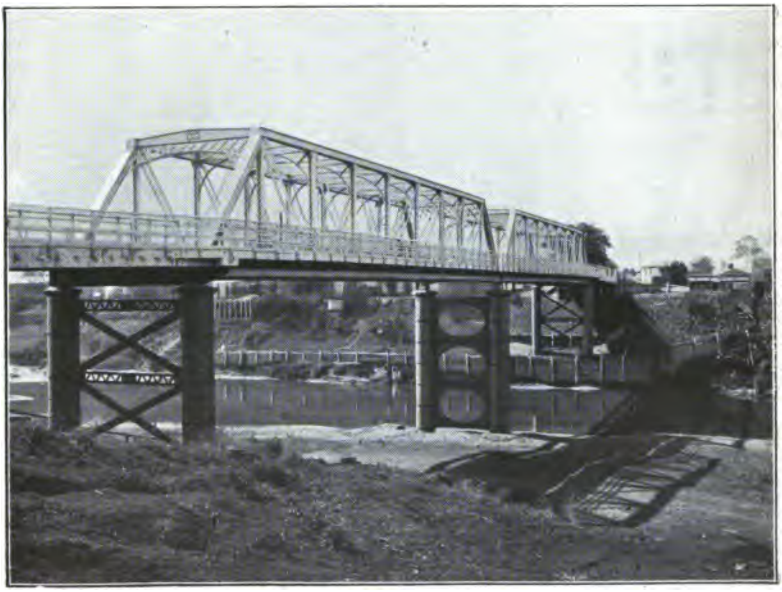


Fig. 112.

Example of a Steel Highway Bridge.

To face p. 290.

Fig 112 shows a steel highway bridge erected over the Hunter River at Dunolly Ford, Singleton, New South Wales. The bridge consists of two 153 ft. steel truss spans, two compound beam spans of 45 ft., and seven 30 ft. plain beam spans. The roadway on truss spans is 20 ft. between kerbs, while a 5 ft. footway is provided on one side. This bridge was designed by the Public Works Department of New South Wales, and erected under their supervision at a total cost of about £14,500, the work being completed in September, 1905.

310. **Pitched Drains.**—The general arrangement of paved street channels is shown in the several figures illustrative of street design in Chapter IX. Pitchers of basalt, granite, or other hard stone make suitable channels when they conform to the specification given in § 261, provided that there is a fall of at least 4 in. per chain, and that the laying is well done. For flatter gradients we have found an invert of brick on edge much more satisfactory. Nine inches is the standard width for pitchers, which are sold by the hundred, and which should average at least 12 in. in length. Four inches is about a minimum thickness for pitchers, 5 in. is better, but 6 in. is by no means excessive in important places. Where a kerb cannot be afforded the pitchers are laid as shown in Fig. 113, but a word of warning against setting the inner pitcher vertical to imitate a kerb, as in Fig. 114, may not be out of place.

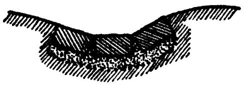


Fig. 113.

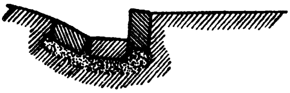


Fig. 114.

Miles of such channel found destructive to scavengers' brooms and difficult to sweep clean, have been altered. Three pitchers make a satisfactory channel where the flow is not great, but four or five are better. The grouting of gutters is best done in cement and sand, about 1 to 3, swept in dry and afterwards sprinkled with water. Where subject to damage by heavy traffic, lime mortar has its advantages. Tar and sand mixed make a cheap and satisfactory grout where the drains are not constantly flowing.

311. Bricked Drains.—As mentioned above, bricks present a smoother face than pitchers. They are, therefore, the more effective in flat situations, and, where paving stone has to be brought long distances, no more expensive. The design shown in Fig. 115, with brick on edge and a kerb on the outside to prevent displacement by vehicles drawn to the roadside, has proved very satisfactory. The arrangement shown in Fig. 116 cannot be recommended for street work, though perfectly satisfactory where there is no traffic, in which case the wooden guard rail can be dispensed with. Heavily loaded wheels are liable to fracture the bricks when laid on their flat.

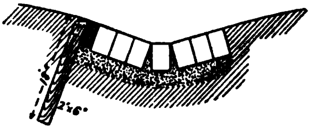


Fig. 115.

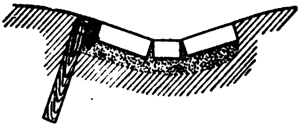


Fig. 116.

312.—Wood-paved Drains.—Wood blocking has been laid in street channels, but its use is not recommended, as, owing to the fact that it is alternately wet and dry, the material soon rots. Apart from sanitary grounds, it is undesirable on the score of extravagance.

313. Concrete Gutters.—Plain and reinforced concrete are both used in street channelling. Reinforced concrete inverts can be moulded to any desired cross section in lengths from 3 ft. to 6 ft.; they are strong, and can be laid and lifted with facility. Inverts of this material are superior to pitchers on account of their smoothness, and are less costly when pitchers have to be transported some distance.

Fig. 117 shows a design for a channel and kerb combined in plain concrete suitable for a town street where the foundation is somewhat wet. The broken stone base can be omitted where the soil is sandy or gravelly. In heavy clay the precaution is sometimes taken to add a 3 in. agricultural drain pipe in the broken stone foundation, which is somewhat increased in thickness. Concrete gutters moulded in place in one continuous mass are liable to crack owing to expansion and contraction. To overcome this trouble it is best to cut the gutter and kerb entirely through every 6 ft. This is best done by inserting a piece of $\frac{1}{4}$-in. sheet iron with a handle in the top as a partition when the concrete is being laid. This is pulled out when the concrete is partly set and the cut is filled in with dry sand.

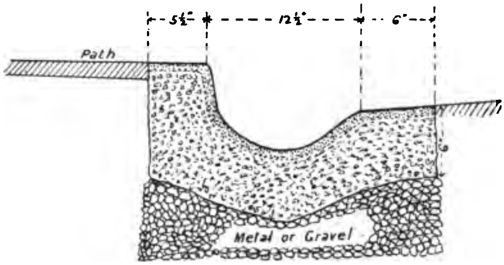


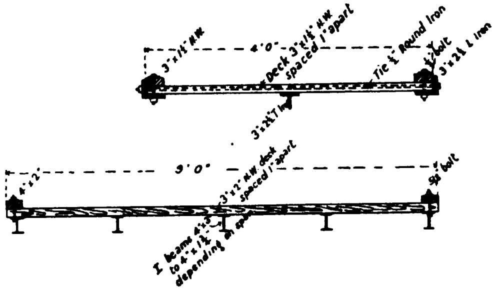
Fig. 117.
Concrete Gutter and Kerb.

Exposed surfaces are rendered with at least ¾ in. of 1 to 1 cement mortar floated in with proper templates of sheet iron. When an even surface is secured, dust lightly with a mixture of cement and fine stone dust, and trowel smooth. After trowelling, finish with a soft brush (a whitewash brush will do), to take out the trowel marks and giving an even texture to the finished work. Keep the surface sprinkled for some days.

314. **Gutter Crossings.**—Crossing over channels may be formed by flattening and widening out the pitching, by pipe culverts, or by the provision of small bridges.

Open paved crossings are easily kept clean, and do not obstruct the waterway. With deep gutters they are inadmissible, and on busy streets the jar and bump given to every passing vehicle is decidedly objectionable. It is well to avoid their use in town streets, and this point should be kept in mind when grading new roads. Generally speaking, it is a good rule to keep the gutters well down. Pipe crossings must not be built in stoneware unless at least a foot of cover is available, though cast iron and reinforced concrete are safe with less. Box culverts with brick walls and timber, or reinforced concrete covers, are the most satisfactory at street intersections, and provide more waterway. For footbridges, or carriage crossings, to private premises, small bridges are generally better than pipes, which are liable to fracture and choke. When there is sufficient waterway, timber stringers can be laid down on suitable sills. If the headway is small it is better to employ steel in the beams, and to bend them to a good camber, so as to facilitate the cleansing of the gutters beneath them.

Fig. 118 shows a cross section of a foot-crossing in such a position. The ends of the deck planks, which are spaced an inch apart by small timber cleats, are supported by angle irons, and held down by small kerbs at each end, themselves secured by bolts. A T iron, or even an angle iron, centrally placed, carries the bulk of the loading.


3"×1½" H.W.
4'0"
Deck 3"×1½" H.W. spaced 1" apart
Tie ½" Round Iron
½" bolt
3"×2½" L iron
3"×2½" T iron
9'0"
4"×2"
3"×2" H.W. deck spaced 1" apart
⅝" bolt
I beams 4"×3" to 4"×1¾" depending on span

Figs. 118 and 119.
Cross Sections of Footbridge and Carriage Crossing where the Waterway of the Channel must not be curtailed.

Fig. 119 shows a design for a carriage crossing in a similar situation, in which small rolled joists are the most economical form of support.

At street corners the arrangement shown in Fig. 120 is advantageous where the gutters are deep, or where the flow is considerable, as it obviates an objectionable step between the footpath and the road.

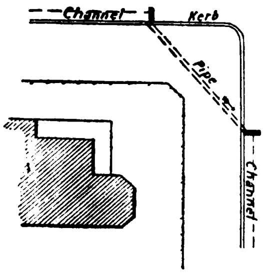
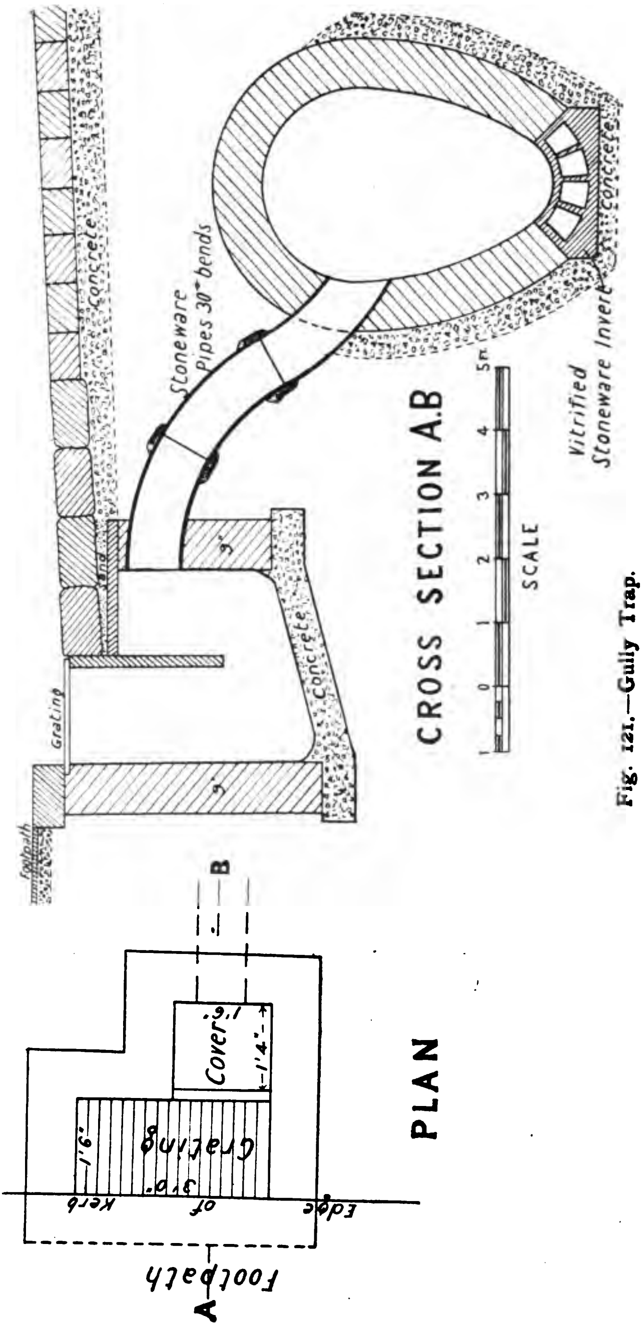


Fig. 120.
Arrangement at Street Corner securing a Level Crossing.

315. **Gullies.**—Where surface drains are connected with storm water sewers, gully pits are inserted in the street channels at suitable intervals, and from them, connecting pipes are laid to the sewers. Except when the velocity of flow in the underground sewer is sufficient to carry forward sand and detritus to an outfall where its presence is unobjec-


CROSS SECTION A.B

PLAN

Fig. 121.—Gully Trap.

tionable, it is highly desirable that the gully pit should intercept all such matter. This is accomplished by providing silt room for that purpose below draw-off level, as shown in Fig. 121, which represents a very useful type of gully, and shows the manner in which it is connected with the sewer by pipe drains. It is built in brickwork on a concrete base, rendered with cement, and with all the corners rounded off. The sloping bottom facilitates cleansing, and the water seal prevents the escape of sewer gases close to the footpath.

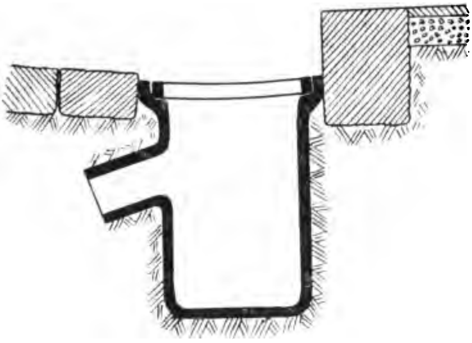


Fig. 122.
Cast-iron Gully without Trap.

Gullies are also made of cast iron, reinforced concrete, and stoneware. They are usually provided with wrought-iron gratings set at gutter level, but cast iron is occasionally specified.

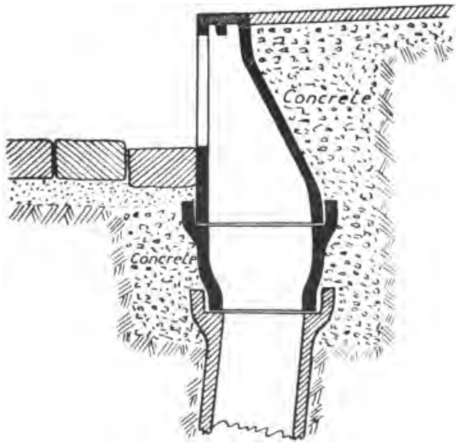


Fig. 123.
Cast-iron Inlet, without Trap.

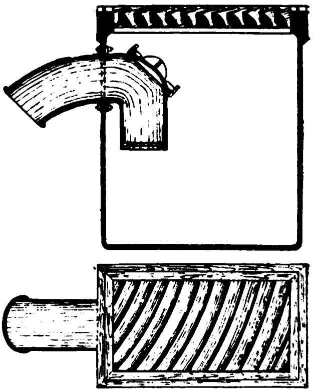


Fig. 124.
Stone's Patent Diagonal-bar Gully Trap.

The bars must be placed at a considerable angle to the line of road, and must be sufficiently open to pass large volumes of water.

Fig. 122 shows a simple form of cast-iron gully without trap, the usual size of which is about 18 in. square and 2 to 3 ft. deep. This type is effective, but more difficult to clean out than is the one illustrated in Fig. 121. A simple inlet, placed on the line of the kerb, is illustrated in Fig. 123. It consists of two castings, jointed and connected with stoneware pipes, leading to an underground drain or sewer. Fig. 124 illustrates Stone's patent gully, in which the grating is made with diagonal bars, which are said to choke less readily than the other grating. Reinforced concrete gullies can be constructed with a monier pipe set vertically on a concrete base, with the top scalloped out to suit the gutter, and a grating provided, but no water seal.

CHAPTER XVI.

MOUNTAIN AND FOREST ROADS.

316. The construction of roads in mountainous country calls for treatment in many respects different from that found advantageous in undulating or level districts. The conditions as regards traffic are in no way analogous to those in towns and cities, and the work has generally to be carried out in sidelong ground. In Chapter II. general principles of economics have been discussed, and the importance of carefully weighing the advantages and disadvantages of alternative routes has been practically illustrated by working out examples in typical cases, such as arise in every-day practice. Location has been fully considered in Chapter III., and considerations determining the most desirable ruling gradient have been given, together with hints on reconnaissance and survey generally. The maximum grade, that should be exceeded only in exceptional cases, has been set down at 1 in 10, and the necessity for the greatest care in the choice of route has been fully emphasised.

317. **Improvement of Steep Ascents.**—Where an existing road ascending the face of a hill has to be graded without deviating the route it is better to gradually diminish the gradient as the summit is approached than to attempt one uniform slope throughout. This arrangement reduces the tractive resistances as the horse becomes fatigued, and permits of heavier loads being taken. The grading, shown to an exaggerated scale in Fig. 125, where the new profile is shown by the broken line, accomplishes this object, and by judicious cut and fill reduces the total lift from the bottom of the hill to the top by the differ-

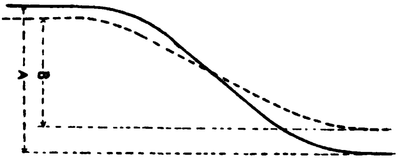


Fig. 125.
Correct Grading of a Road ascending the Face of a Hill.

ence between the length of the lines **A** and **B.** In every case the meeting points of all grade lines should be rounded off by vertical curves.

318. Width of Curvature of Mountain Roads.—Mountain roads so frequently traverse poor country that, more often than not, elaborate construction cannot be justified. Very frequently roads in such situations are little more than ledges cut in the hillside sufficiently wide to accommodate traffic. The narrowest roads in side cutting are built with a carriage-way 8 ft. wide, which is increased to 10 ft. wide on curves of 75 to 100 ft. radius, and to 12 ft. on curves less than 75 ft. radius. No curve should ever be less than 25 ft. radius, but where heavy loads are to be hauled up hill, this should be increased to 40 ft. or the whole tractive force will devolve upon the shafters when rounding the turn, and the loading will be correspondingly reduced. For this reason the gradient should always be flattened at sharp curves.

Where reverse or S curves are required there should be a short length of straight connecting the curves, as shown in Fig. 126. Concave curves should, however, be connected by a curve as shown in Fig. 127, and not by a straight.

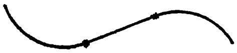


Fig 126.

Reverse Curves with Length of Straight between.

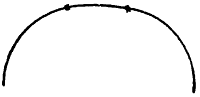


Fig 127.

Showing Connection between Concave Curves.

On such narrow roads as mentioned above, it is impossible for vehicles to pass, and pass-bys or turn-outs, on an almost level grade, at least 75 ft. long by not less than 12 ft. wide, must be provided within sight of each other if practicable, but never more than about half a mile apart. The number of passing places depends to some extent on the amount of vegetation obstructing the view. In forest country, where drivers cannot see any great distance in front of them, they must be spaced closer than in open places, where approaching vehicles can be seen a good way off.

Where the road is sufficiently important to warrant provision for the passing of vehicles at any point, the minimum width between toe of cutting and edge of bank should be 15 ft., of which about 2 ft. are occupied by an open drain on the inner edge, and 1 ft. by the fence, leaving 12 ft. available for traffic. Where possible, however, 20 ft. or over should be secured, as shown in Figs. 128 to 130.

319. Cross Section.—In sidelong ground an effort should be made to balance, as far as possible, the cutting and filling transversely, due regard being had to the fact that most earths compact into less space than they originally occupied, whereas most rocks expand to about 50 per cent. in excess of their volume *in situ*. For further information on this subject refer to § 54, Chapter IV. In such situations it is generally inadvisable to cart forward, except where a gully is to be banked across or approaches to a culvert or bridge are required. Then the centre line on each side of the embankment should be so located as to provide a surplus of cutting to be used for the purpose; the design calls for considerable thought, and affords scope for skilful treatment. Opinions differ regarding the profile of roads in side cutting. Some contend that the transverse fall should be wholly towards the hill, as shown in Fig. 128, to prevent erosion of the slope of the embanked portion; others hold that the road should be crowned in the ordinary way with transverse slopes in both directions, as shown in Figs. 129 to 131. The first-mentioned cross-section tends to wear hollow, but is desirable on sharp curves, where the centre line is concave to the hill, and where superelevation,

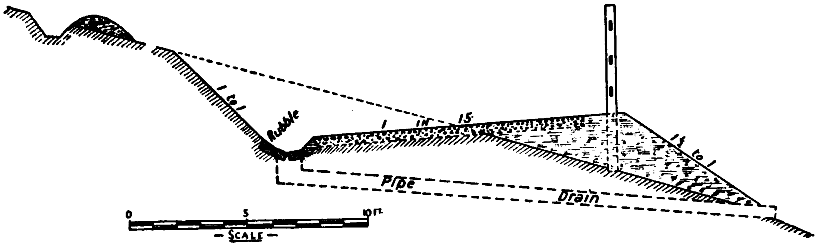


Fig. 128.

Cross Section of Mountain Road showing Cross Drainage Arrangements.

to provide for the safe passage of rapidly-moving vehicles, must not be neglected. When rounding gullies the road is curved in a direction opposite to that on spurs, and the former being in the wrong direction for superelevation is impracticable. For this reason the cross-section must be arranged to suit the requirements. All these points must be considered when the design is being prepared, as they materially affect not only the quantities of excavation and embankment, but the utility of the road. In most instances it is better to crown the formation, as shown in Fig. 129, except at sharp turns, when the slope must be wholly in one direction. In every case catchwater drains of ample capacity are required, within the limits of the road reservation, to intercept storm water that would erode the batter of the cutting and overcharge the watertable of the formation. These must be conducted to some natural channel, or the waters conveyed by them passed under the road by pipe drains or culverts at sufficiently frequent intervals. Stoneware or monier pipes make excellent cross drains if arranged as shown in Fig. 128. They are generally superior to open crossings, which must be paved, and so arranged as not to unduly jar passing vehicles.

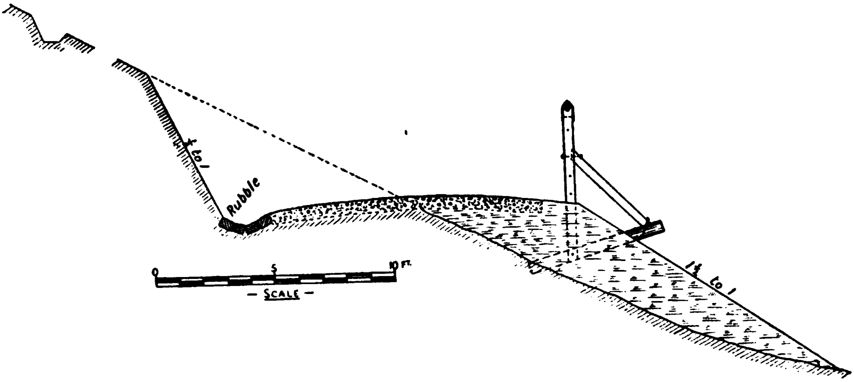


Fig. 129.

Cross Section of Road in Side Cutting.

The absence of such catchwater drains, and neglect in the maintenance of those originally excavated, is painfully apparent in some districts, and indicates short-sighted policy that should be apparent as such to all. When funds permit, it is advisable to roughly pitch the watertable drains, except where sound rock is exposed. Some teamsters have an unfortunate habit of braking the progress of their vehicles on steep inclines by running the wheels hard against the slope of the cutting, and thereby damaging, not only the slopes, but the watertables in addition, so that they soon gutter out, and frequently become dangerously deep.

It may not be out of place here to refer to the damage done to steep roads by the use of drag logs to arrest the motion of descending vehicles, and by iron shoes placed on locked wheels. The use of such appliances should not be permitted on made roads, as they cause incalculable damage.

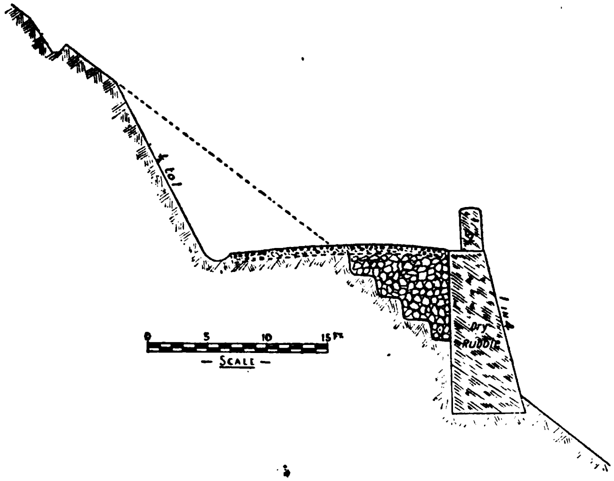


Fig. 130
Side Cutting and Embankment with Retaining Wall.

The safety of the travelling public using side-cutting roads in steep country should invariably be safeguarded by the provision of fences or walls on the outer side. Exception is sometimes taken to the use of fences on the ground that, owing to their flimsy nature, they afford no real protection. While stone walls are stronger than the average fence, their cost in a young country is prohibitive in most situations, and substantial fences are all that can be afforded at present. In every such fence at least one rail should be provided. Wire fences are not easily seen at night, and are dangerous; the use of barbed wire is quite inadmissible. Where stone parapets can be afforded they should never be less than 3 ft. high, and 1 ft. 6 in. thick if laid in mortar, or 2 ft. long if built dry. In any case the coping should be of heavy stones set transversely to the line of the wall in mortar, and well lime whited.

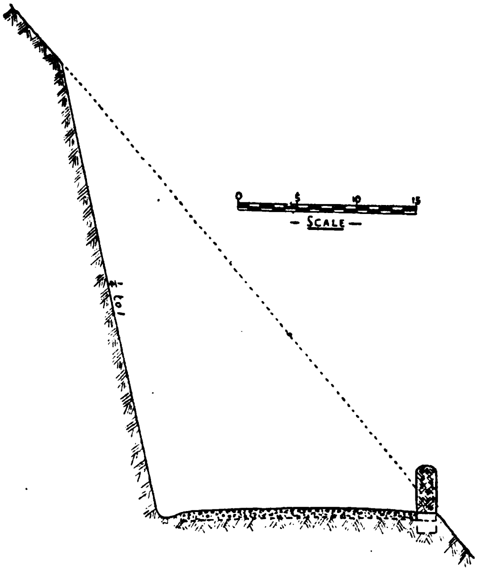


Fig. 131.

Mountain Road wholly in Cutting, where the slope of the hillside exceeds the angle of repose of the loose material.

320. Cross-Section on Steep Side Slopes.—Where the natural side slope is unusually steep, retaining walls may be built to support the embanked portion, or alternatively the road may be placed wholly in cutting.

In Fig. 130, representing a road in rock excavation, the first-mentioned course is adopted, the retaining and parapet walls being built on a firm foundation in dry rubble, with stone produced from the excavation. The dimensions of retaining walls, which may be built as dry rubble or set in mortar, are best proportioned by Trautwine's rules, which have been found reliable.

Fig. 131 shows a case where, owing to the steepness of the side slope exceeding the angles of repose of the earth and loosened rock, the best course was to place the road wholly in cutting. The rock was blasted out and rolled down the hillside, only so much as was required for the construction of the parapet wall, and for breaking down for road metal, being retained.

Fig. 132 illustrates a remarkably fine mountain road in France, with expensive retaining wall construction immediately above a railway line. Fig. 135 shows a New Zealand road in precipitous country, where retaining walls have been extensively used, with comparatively low stone walls for the protection of traffic.

Vertical faces of cliffs are about the greatest obstacles to road construction. Cases are known where timber frameworks, supported by inclined struts, have had to be adopted in such situations. Provided that the rock is sufficiently sound, the best course is to blast out a half-tunnel of the shape shown by heavy lines in Fig. 134. The bore holes for the first blast are shown by full lines, those for the second by broken lines. Fig. 136 shows a view of an existing road of this description.

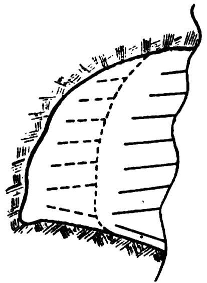


Fig. 134.
Cross Section of Road Cutting on the Face of a Cliff.

321. **Blasting.**—The use of explosives has been touched upon in Chapter VIII. Blasting powder is admirably suited to the softer rocks, including shale, most sandstones, limestones, mica-schist, and the papa rock of New Zealand. A small charge of one of the higher explosives is required to chamber or spring the bottom of the hole into a bulb-like shape. In sandstone such a charge amounts to about 1-10 lb. per cubic yard of rock to be dislodged. Of blasting powder allow from ¾ to 1¼ lbs. per cubic yd. in ordinary side cuttings. Remember that, as explained in § 132, the cost of

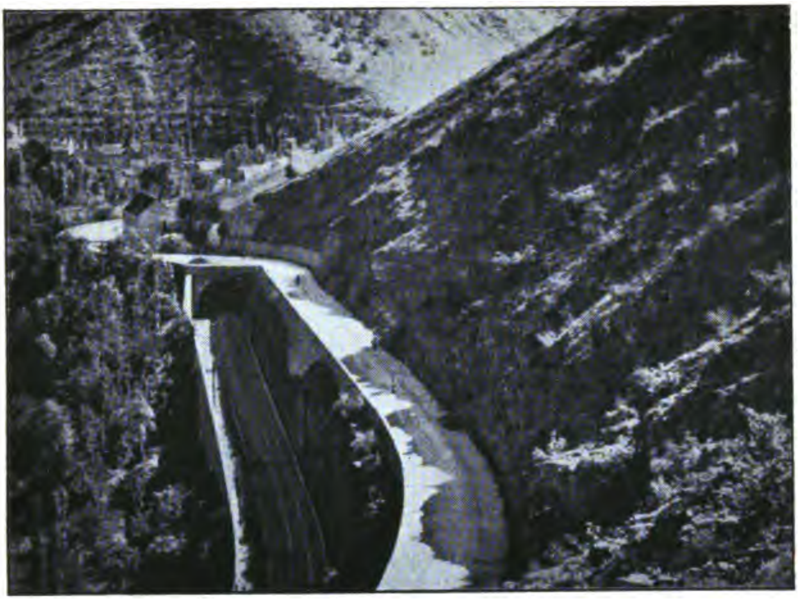


Fig. 132.
A Remarkably Fine Mountain Road in France.

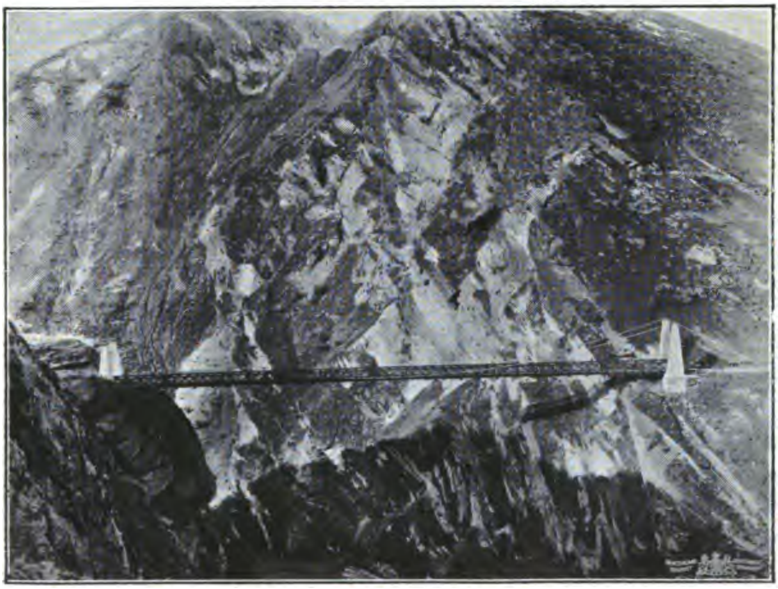


Fig. 133.
Suspension Bridge at Skipper's Gorge, New Zealand.

To face p. 304.

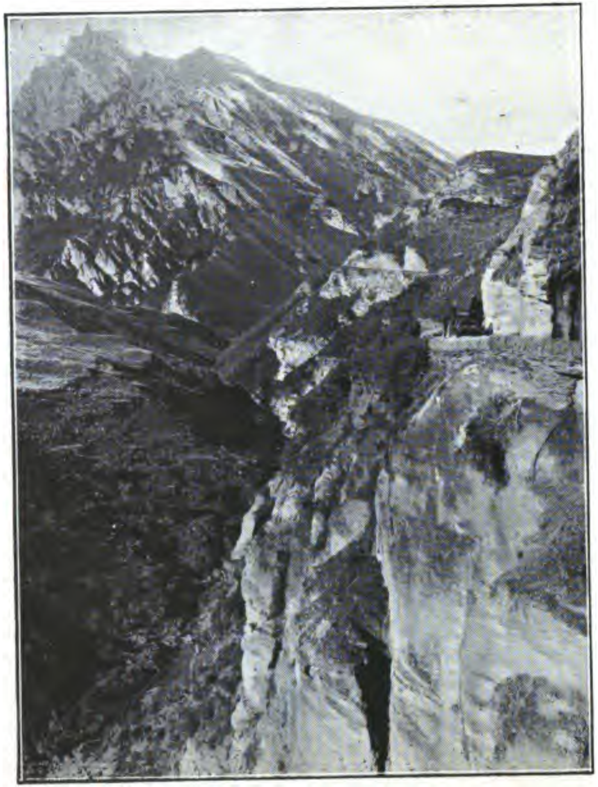


Fig. 135.—Mountain Road, Skipper's Gorge, N.Z.

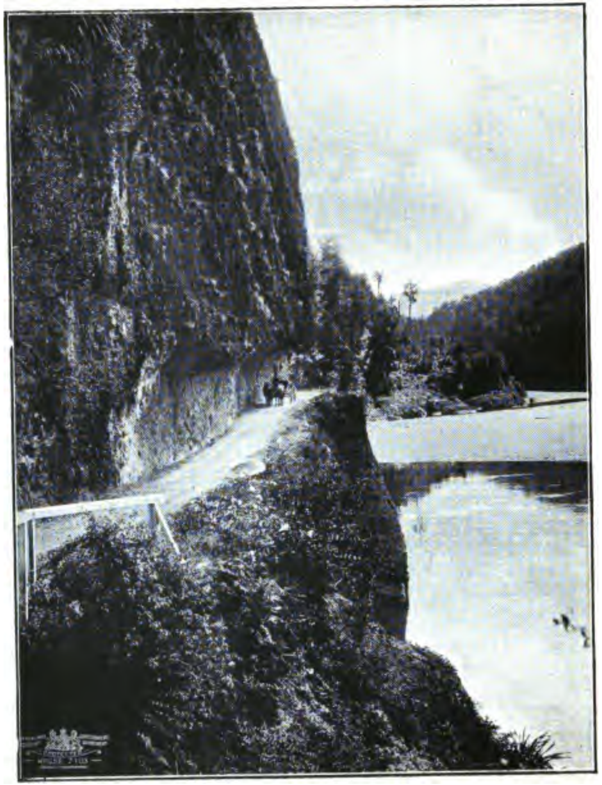


Fig. 136.—Hawks' Crag, Buller Gorge, N.Z.

To face p. 304.

blasting is greatly increased where the bore holes are necessarily shallow.

322. Tunnels.—Tunnels through hills are very occasionally required on mountain roads in very difficult country, though it goes without saying that every effort should be made to avoid these costly excavations. An example of a tunnel on a highway is to be seen on the Grafton Road, N.S.W. Natural tunnels are sometimes taken advantage of, as for instance on the road leading to the Cave House at Jenolan, N.S.W.

323. Metalling.—When the traffic is light, and the material sufficiently stable, metalling may, under certain circumstances, be dispensed with, provided that care is taken to keep both the foundation and surface well drained. Most mountain and forest roads, however, require metalling, more especially where the surface is shaded from the sun, and remains pretty constantly moist. Metalled strips in the centre only are of very little use, as traffic tends towards the inside running, especially on curves. For this reason it is better, if the whole cannot be metalled, to improve the most trafficked portion irrespective of considerations of symmetry. The quality and thickness of metal required have been already discussed in Chapters VIII. and IX.

324. Bridges and Culverts.—Long bridges are very costly, and should be avoided as far as possible on mountain roads. Fig. 133 shows how a steel suspension bridge has been utilised to bridge a chasm on a mountain road in New Zealand. In rough country, where the transport of materials is expensive, timber growing near the site should be utilised as far as possible. The design of bridges is outside the scope of this book, but examples of culvert construction and bridges of several types are shown in Chapter XV. Where mountainous properties are intersected by roads, heavy claims for compensation on account of severance can be minimised by the provision of subways for the passage of stock as well as of drainage waters. The structures are merely culverts, such as shown in Figs. 107 and 108, generally built of round logs and hewn timber, but with walls high enough to permit the passage of vehicles if necessary. Where subways are impracticable, gates must of necessity be provided.

325. **Cost of Mountain Roads.**—The cost depends so much upon the nature and extent of the clearing, number and length of the bridges and culverts, the quantity of earth and rock excavation, and upon other local conditions, that figures of general application cannot be given. The cost of side cutting where rock is encountered is rarely less than £200, and is frequently in the vicinity of £400 per mile, or even more. Estimates can be based only on actual quantities and a full knowledge of the conditions.

CHAPTER XVII.

SPECIFICATIONS AND CONTRACTS.

326. Construction carried out by contract should invariably be the subject of properly drawn-up documents, the duty of preparing which devolves upon the engineer. Contracts are of several kinds, as under:—

(a) Schedule of rates contract in which the work to be done is scheduled as nearly as the quantities can be forecasted, and paid for at prices mentioned in the accepted tender. In another kind of schedule of rates contract the engineer assigns prices to the work as scheduled in each item, and tenderers are asked to state the percentage above or below those particular rates at which they are prepared to carry out the work. The first-mentioned system is generally preferred.

(b) Lump sum contracts are satisfactory when the quantity of work to be done is definitely settled, and is not likely to be exceeded. Where the quantities are indefinite trouble generally arises with the contractor in fixing the rates for extra work unless a schedule is appended to the tender. Most engineering works are best carried out by schedule of rates contracts in preference to lump sum, even when a schedule is attached to the latter.

(c) Contracts are sometimes entered into on a percentage basis, under which the contractor is paid the cost, whatever it may be, plus a percentage previously agreed upon. Under this system there is no inducement to economise; in fact, the more the contractor spends the greater is his profit.

(d) Cost plus a fixed sum contracts have come into limited favour, and are more workable than the last mentioned. The inducement the contractor has to hurry him on is the fact that his profit is predetermined, and that every delay keeps him out of another job, and ties his plant up so much the longer.

System (d) has its advantages on difficult jobs where the risks are great, and where tenderers bid high to cover themselves against possible losses. On the whole, system (a) is the best for most purposes. We propose to discuss briefly the essentials of well-drawn contracts only so far as they come within the province of the engineer.

327. **Contract Papers.**—The documents comprising contract papers include form of tender, conditions of tendering, general conditions, deed or agreement, schedule, specification, and drawings. The preparation of each of these will be dealt with as far as possible separately below.

328. **Form of Tender.**—The following is a specimen form that may be used in schedule of rates contracts. It is usual to supply these to bona fide tenderers without charge:—

TENDER.

SCHEDULE OF RATES CONTRACT.

To..

Under and subject to the Conditions of Tendering annexed hereto the undersigned do hereby tender and offer to execute and perform the several works and provisions and supply all labour and materials and everything of every kind respectively named, shown, described and alluded to in the Conditions of Contract and Schedule of Quantities and Rates annexed hereto, and in the Specification, to be executed and supplied on the part of the contractor, for the [The engineer is to here describe very briefly the nature and extent of the works.] in conformity with the said Specification and under and subject to the Conditions of Contract annexed hereto at the rates set out in the said Schedule of Quantities and Rates. The undersigned agree to be bound by and submit to the said Specification, Conditions, and Schedule of Rates.

The total amount of this tender calculated according to the said Schedule of Quantities and Rates is the sum of*..........£.......s........d.

Witness....................hand this...........day of......................190

Signature of Tenderer..

Postal Address...

Date...................................

Amount of Deposit enclosed £..........................

Witness to the signature of Contractor...

[Note that the schedule is very often printed below the form of tender on the same sheet of paper.]

329. **Conditions of Tendering.**—These are required so that the terms under which tenders are received, and accepted if so desired, may be defined. The following specimen has been successfully used for some time, and what would be blank spaces in a printed form are filled in as they would be for a contract let by a private person. For the word "Proprietor," substitute "Council," "Company," "Trustees," &c., as required. It will be noted that this document stipulates requirements as to deposit, &c., and reserves to the proprietor the right to reject all tenders. The document, in short, is intended to indicate the whole of the procedure up to, but not after, the signing of the contract deed or agreement.

CONDITIONS OF TENDERING.

Schedule of Rates Contract.

1. The whole of the works set forth in the Schedule of Quantities will be let in one Contract subject to the General Conditions of Contract.

2. Each tenderer must send in his tender on the form annexed to these Conditions, having attached thereto the Schedule of Quantities and Prices, the said Schedule, including the provision money or moneys, being filled up with the rates and amounts at which he tenders. Tenders must in all cases be for the works as specified,

---

* The contractor is to here state in ink the total amount as shown in his Schedule of Quantities and Rates attached INCLUDING THE PROVISION, and he must also forward herewith a copy of the Schedule of Quantities, Rates and Amounts, showing in ink how the amount of his tender was arrived at, together with the Conditions of Tendering and Contract. With the exception of filling in the rates and amounts the tenderer must not make any alterations or additions to the Schedule or conditions.

and no condition is to be inserted contrary to or differing from those in the specification. Any tender which does not comply with these conditions will be liable to be rejected.

3. Tenderers must mark distinctly on the envelopes enclosing their tenders, thus—

Tender for.........................

4. The Contract to be tendered for is a Schedule of Rates Contract, and the sum to be inserted in the tender as the total amount shall not be taken to mean a lump sum, but is merely inserted to enable the engineer to at once determine which tender is the lowest.

5. A preliminary deposit as a guarantee of good faith, and of the amount stated in the advertisement for tenders, must accompany each tender and be in cash, post office order, approved bank notes, deposit receipt, or marked cheque, the latter to bear date of the last day for receiving tenders, otherwise such tender may be deemed to be absolutely rejected.

6. After any tenderer, having made such deposit, has been declared to be the lowest approved tenderer, if it be found that there is any discrepancy between the total amount of his tender and the amount arrived at by moneying out the given quantities, in the Schedule of Quantities at the rates set against them, then the said tenderer must, within three days or such further time as may be allowed by the engineer, alter the rates in the said schedule so that when the quantities are moneyed out at such altered rates the total amount shall agree with the total amount of his tender, and if the tenderer shall not within the time allowed rectify the discrepancy as aforesaid or if for any reason either before or after the acceptance of the tender, the tenderer shall withdraw the tender or decline to enter into the contract, the moneys lodged by him as a guarantee of good faith shall be absolutely forfeited to the [Proprietor] as liquidated damages, and such tender will be deemed to be absolutely rejected unless the [Proprietor] shall otherwise decide.

7. If any tenderer declared to be the lowest approved tenderer shall have complied with the foregoing Conditions, a letter notifying the acceptance of his tender, subject to the Conditions stated in such letter, will be addressed to him, and he must thereupon within the time given to be stated in said letter deposit with the [Proprietor] a sum equal in amount to [five] per cent. on the total amount of the tender in cash or approved bank deposit receipt to the credit of the [Proprietor] to be held as security for the due performance of the Contract; and he must within the time given as aforesaid execute the Contract Deed, having the Specification, Conditions of Contract, and Schedule of Quantities and Rates therein referred to annexed to said Deed, such Schedule of Quantities and Rates to be first filled up with the rates and amounts at which he tenders or the altered rates and amounts as per Clause 6 above as the case may be. In the event of his failing to make such deposit or to execute such Contract Deed within the time aforesaid his tender shall be deemed to be absolutely rejected unless the [Proprietor] shall otherwise direct, and all moneys already deposited by him under these Conditions shall be absolutely forfeited to the [Proprietor] as liquidated damages. Should the lowest approved tenderer fail to make deposit or to execute the Contract Deed as aforesaid the [Proprietor] may proceed to declare

the next lowest approved tenderer to be the lowest approved tenderer, and deal with him as in Clauses 7 and 8, and so on till an approved tenderer shall have complied with this Condition.

8. The deposit provided for in Condition 5 will be credited to the tenderer as in part payment of the cash security required by the letter of acceptance mentioned in Condition 7 above.

9. The [Proprietor] shall not be bound to accept any tender, and the acceptance of a tender shall not be deemed to complete the contract; and although the tenderer shall have complied with all the above Conditions on his part to be performed the [Proprietor] may by notice to the tenderer to that effect annul the acceptance of any tender at any time before the required deposit has been accepted and the contract executed, but in such case such tenderer shall he entitled to receive all moneys deposited by him under these Conditions, and until the required deposit has been accepted and the contract executed by the contractor he will not be allowed to proceed with the works of the contract, and he will not be entitled to claim for any loss or damage through not being allowed to execute the contract and proceed with contract works.

10. Every notice to be given to a tenderer may if the [Proprietor] think fit be posted to the tenderer's address given in his tender, and such posting shall be deemed good service of such notice, and the time mentioned in or under these Conditions for doing any act after notice shall be reckoned from time of posting same.

11. The word tenderer in these Conditions shall be deemed to include two or more persons, the word "his" may also mean "their" and the word "he" may also mean "they."

12. The word [Proprietor] in these Conditions shall be deemed to signify..........................

330. General Conditions.—The object of these is to define general conditions applicable to all or most contracts as distinct from the specifications which are intended to describe the particular works, materials, and construction in detail. The line of demarcation is hard to define, but so long as the whole of the essentials are included in one or other of the documents, and there is no conflict between them, trouble should not arise in their interpretation. The usual practice is to make the general conditions, which are usually printed, as full as possible, so that the specification may be curtailed in length.

The general conditions, of which a specimen draft is given below, have been found satisfactory, and with modification to meet any local conditions may, we think, be safely accepted. The blank space in the form is here filled in with the word "Proprietor." As drafted, the conditions are applicable to either a schedule of rates or lump sum contract in which a schedule of prices is included. Taking the clauses seriatim, the following points come under observation:—

Under clause 3 preferably a fixed sum, inserted in the schedule by the engineer, but sometimes a percentage on the total of the preceding items, is included to cover extras and unconsidered trifles if duly ordered. Here it is advisable to emphasise the necessity for issuing all instructions in writing. In the event of disputes arising written directions speak for themselves. Careful contractors expect written instructions. By clause 6 the engineer may alter the drawings, but in 13 provision is made for a variation in the price if by such alteration the scheduled prices are not to apply. The last paragraph of clause 6 is necessary to guard against trivial claims on account of no mention being made of minor works or fittings that are obviously required.

Clause 9 is a very necessary one, but should be administered with caution. It is unwise for the engineer to interfere unduly or to take the work out of the contractor's hands. If he does the question of divided responsibility immediately arises.

Under clause 13 the engineer retains the right to order any extras, alterations, &c., and the contractor is bound to carry them out. Without such provision a contractor might shut down the works should he refuse to carry out any unexpected work which, though obviously necessary, had not been scheduled. It is stipulated that the prices to be paid for any work, which in the opinion of the engineer is not provided for in the schedule, shall be fixed by the engineer. This provision is thought by some to be unfair, but if the prices fixed are unreasonably low, the arbitrators or the courts will not uphold the engineer. An alternative to this would be to pay actual cost, plus, say, 10 per cent. thereon for any work not scheduled.

Exception may be taken to the proviso in 13 prohibiting any extension of time on account of extras. The object of this is to prevent trivial claims on account of extras of a minor nature. The saving clause "unless the contrary is specified" should not be passed over without consideration when drawing the specification. For an example see the wood blocking specification, § 248.

Under clause 15 copies of drawings may be taken by the contractor; the more usual way is for the engineer to supply them at a uniform charge of 1 per cent. on the total cost, unless, as is sometimes the case, arrangements are made by the Council that copies are to be supplied gratis.

It will be noted that the contractor under clause 16 has to take the responsibility of setting out the works. This is better in every way than to throw that duty on the engineer.

Payments to be made under clause 17 should be at intervals corresponding in some way with the contractor's pay days. If he pays fortnightly progress payments should be made either fortnightly or monthly in preference to every three weeks. 75 to 80 per cent. on the value of the labour can usually be allowed. On materials it is safe to allow 85 per cent., and the general conditions can be varied to provide for this being done.

Clause 21 burdens the contractor with responsibilities against accident and disaster. Exception is sometimes taken to clauses of this nature on the grounds that the employer and not the contractor should take these risks. Generally speaking, however, this clause is necessary, because without it many contractors would cheerfully take risks, knowing that if they escaped, the gains would be theirs, while any loss sustained would fall on their employers. The question is one of policy, and it is occasionally advisable to indemnify the contractor against losses by flood, for instance. When the risks are so great that tenderers will add a large percentage to cover them, a contract on the basis of cost plus a fixed sum should be considered. Provided that the contractor carries out his work faithfully in strict accordance with the specification or other written directions, he cannot be held responsible for failures that are proved to be due to errors of design, the responsibility for which he has not shouldered.

The penalty for delay mentioned in clause 25 is frequently not enforced, though there are many cases in which it should be. In urgent works a very fair arrangement, and one that is sometimes adopted, is to provide for the payment of a bonus for early completion. This gives the contractor a prize to work for, and is useful in securing prompt completion.

Clause No. 26 provides that disputes are to be referred to arbitration in a manner clearly set forth. Many contracts, especially those drawn up by Government departments, appoint the engineer sole arbitrator. To make a man judge in his own cause is palpably unfair, not only to the contractor, but to the engineer himself. In contracts containing this provision the personality of the engineer enters largely into the estimates of the contractor, who naturally safeguards himself against possible losses through unfair or tricky decisions.

The engineer should be sole judge of the fitness of materials, but cannot be expected to decide legal questions relative to the fulfilment of the contract. Resort to arbitration does not always bar the way to a subsequent appeal to the law courts.

Clause 27 provides for the cancellation of the contract under circumstances which occasionally arise.

331. General Conditions.—Extent and Nature of Contract:—

THIS CONTRACT is for the..

....

and is to be carried out under the following conditions:—

Supervision of Works.

1. That the whole of the works of this contract are to be carried out under the control and to the entire satisfaction of the Engineer, and should he appoint a Superintendent or Clerk of Works, the Contractor shall receive instructions from him as coming from the Engineer himself.

Municipal By-Laws.

2. That the Contractor shall comply with all Corporation, Municipal or other local By-laws and Regulations, and pay all fees lawfully demanded by any local authorities for matters in connection with this contract.

Provision.

3. The provision in the Schedule of Quantities and Rates is a provision for extras, additions, enlargements, deviations, or alterations to or in said works; but it is to be distinctly understood that the whole or any part of the sum represented by said provision may or may not be expended in any one kind of work specified, or may be expended over all the various kinds of works, or no part of it may

be expended at all. When the whole or any part of the said sum has not been expended, the same shall be deducted from the amount of the contract moneys.

Contractor to Proceed with Works Immediately.

4. That the Contractor shall immediately after he gets possession of the ground or works, or any part thereof respectively, commence the works of the contract, and proceed with diligence and expedition to execute the same; and he shall not fail to make sufficient progress with the work, nor shall he stop the same unless required to do so by the Engineer, who shall have power to order suspension.

Possession of Ground.

5. Possession of the ground or works shall not be deemed to give the Contractor exclusive possession, but only a limited possession, in order to enable him to perform the works of the contract, and the [Proprietor] may at any time take possession for any purpose whatever.

Drawings, etc.

6. That the Drawings already prepared are intended to give a general idea of the character of the works, but the Engineer reserves to himself full power to make any alteration therein or addition thereto, and to supply any fresh detail or general drawings he may think fit.

If in the execution of the works it shall be found that anything has been omitted or misstated either in the said Drawings or Specification, which is necessary for the proper performance, completion and stability of any part or parts of the works, the Contractor shall, at his own expense, execute the same and provide whatever may be requisite for so doing. Any written dimensions on the said Drawings shall be taken in preference to the scales mentioned on the Drawings, and anything contained either in the said Drawings or Specification or Conditions shall be equally binding on the Contractor as if it were contained in each, and in case the written or figured dimensions on the said Drawings shall disagree with the scaling, or in case there shall be any variance, discord or discrepancy between the said Drawings, Specification, Schedule of Quantities and Rates and Conditions, or any ambiguity or clerical error in them, the same shall be rectified by the Engineer if thought necessary by him, and the Contractor shall not be entitled to make any claim or demand for compensation or damage on account of such variance, discord, discrepancy, ambiguity or clerical error. If neither the said Drawings, nor the Specification, nor the Schedule of Quantities and Rates, nor Conditions contain any notice of minor parts, the intention to include which is nevertheless clearly to be inferred, and which parts are obviously necessary for the completion and stability of the work, all such parts are to be made and executed by the Contractor without extra charge.

Contractor to be Represented.

7. That the Contractor shall at all times during the progress of the works when he is not personally superintending them, have a responsible agent or overseer stationed thereon to act on his behalf, and shall not relet or underlet the works or any part thereof without the permission of the Engineer.

Power to Order the Discharge of Workmen.

8. That the Engineer may order the dismissal within twenty-four hours of any workman or other person engaged on the works, and in the event of the Contractor neglecting or refusing to comply with such order all progress payments may be stopped until the order is complied with.

Order of Works.

9. That the Engineer shall have power from time to time and at any time before or during the construction of the works to direct the Contractor to commence, carry on, make, excavate, and construct the works of this contract in such order of time or locality or work as the Engineer may so order and direct, provided such order and direction shall be in writing.

That the Engineer have power to withhold any progress or final certificate until all orders given by him are carried out to his satisfaction.

Providing Materials, Labour, etc.

10. That with the exception of such materials, if any, as are specified to be supplied by the [Proprietor], the Contractor shall provide at his own cost all carriage, materials, labour, tools, plant and everything necessary for the proper execution and completion of the several works, all of which materials, plant, etc., are to be approved by the Engineer before being used. The Contractor is also at his own cost to provide for keeping all trenches and excavations free from water, and for preventing all slips of ground into them; also all watchmen, lights and fencing necessary to prevent any accident or public or private damage or loss during the progress of the works and until the completion of the contract. All plant or material brought upon the land or the site of the works for use upon this contract are to be considered the property of the [Proprietor] until the completion of the contract, and the Contractor shall not take away such plant or material without the written authority of the Engineer.

Quality of Materials and Work.

11. That all the materials used are to be of the best of their respective kinds, and all works are throughout to be executed conformably with the several drawings and details prepared or that may be prepared for that purpose, and herein referred to, in strict accordance with the provisions of the Specification, and in the best, most substantial and workmanlike manner, and to the satisfaction of the Engineer, and should any work not be so executed it shall be immediately altered and amended at the expense of the Contractor.

Removal or Retention of Inferior Materials.

12. That the Engineer may order the removal from the works of any materials, whether fixed or not, that may appear to him to be of an inferior description, and the Contractor shall remove the same within forty-eight hours after a written notice to that effect given to him by the Engineer, and in case of neglect or refusal to remove the same the [Proprietor] shall have power till such material is removed to withhold payment of all sums of money that may be due to the Contractor, but should the Engineer so elect any inferior materials or workmanship may be retained, and in every

such case the Engineer shall have the power to fix the price of such material or workmanship, and the Contractor shall be bound by his decision.

Extras, Additions, Enlargements, Deviations, Alterations, or Omissions.

13. That the Contractor is to make and execute in like manner as aforesaid any extras, additions, enlargements, deviations, or alterations in the works or the position of them, which the Engineer may from time to time before the commencement or during the progress of the works by an order in writing require; and the Contractor shall have no claim for loss, damage or compensation on account of any extras, additions, enlargements, deviations or alterations, nor shall he be entitled to any extension of time on account of such extras, additions, enlargements, deviations or alterations, unless the contrary is specified.

That the Contractor is to make and execute all such extras, enlargements, deviations or alterations at and for the several rates set forth in the Schedule of Rates annexed hereto, but if in the opinion of the Engineer any such works shall differ from those described in the contract, then the rates for such works shall be determined by the Engineer, whose decision shall be accepted by both parties.

The Engineer shall have power to order the omission of any particular portion of the works of this contract, and the Contractor shall have no claim for payment, loss, damage or compensation on account of such omission.

Measurement.

14. That all measurements are to be net, and to be determined by the most approved and accurate methods. The cubic contents of all excavations will, unless specified to the contrary, be measured from the cuttings from which the materials have been taken, and not from the embankments or spoilbanks. Lineal measurement means the actual net length. The Contractor or his representative must be present at all measurements, and assist in making same if required.

Copies of Drawings, etc.

15. The Contractor may at reasonable times take copies, at his own expense, of all or any of the plans and specifications.

Setting Out Works.

16. The Contractor shall set out accurately, at his own expense, all the works comprised in this contract in accordance with the plans prepared.

Payments.

17. Payments will be made at intervals of........or thereabouts as the works proceed on the certificate in writing of the Engineer, at the rate of [75] per cent. on the value of the work actually done, and of such approved materials as may be on the ground, such payments to be in sums of not less than £...........at a time, the Engineer to value the materials. The balance to be paid to the Contractor within.........days after the Engineer shall have certified that the works have been satisfactorily completed. The deposit

security will be retained till the expiration of the maintenance period, when, should the Engineer certify that everything is satisfactory, it will be returned. Should no maintenance be specified, the deposit will be returned with the final payment.

Progress Payments Without Prejudice.

18. That no certificate given to the Contractor for the purpose of any payment shall prevent the Engineer at any time before the termination of the contract from rejecting all unsound or improper work or materials, and notwithstanding the giving of any certificate that portions of the whole of the works have been satisfactorily performed, the Engineer may require the Contractor to remove or amend at any time up to the expiration of the period of maintenance any work or materials that may be found not to be in accordance with the contract, and the Contractor must amend or remove at his own cost all such work or materials when so required by the Engineer.

Board of Health Regulations to be Complied With.

19. That the Contractor shall comply and so far as lies in his power cause all persons in his employment to comply with all regulations, directions, by-laws and orders of the Central or Local Board of Health, including the provision of proper latrines for his workmen.

Opening Up.

20. That at any time before giving the final certificate at the expiration of the period of maintenance, the Engineer may require the Contractor to open up to any necessary depth any portion of the works for inspection. Should the parts so opened up prove to be in accordance with plans and specifications, payment will be made at the scheduled rate for day labour for the time occupied in opening up and reinstating. Should the work, however, prove unsatisfactory, it is to be at once made good by the Contractor, and no allowance will be made either for opening up as above or making good the defects, and the maintenance period may be extended, as the Engineer may consider necessary, for its thorough examination and the repair of all portions found defective.

Liability of Contractor for Defects, etc.

21. That the Contractor shall maintain and deliver up in perfect order and repair all the works comprised within this contract, and shall be solely liable and responsible for all defects or failures from any cause in the same, until the work is completed and taken over, or until the Engineer shall certify that the whole of the works of this contract are finally and satisfactorily completed, whether the said defects arise or accrue either before or after the specified time of completion, from defective construction, bad materials, or any cause within the Contractor's control. He shall also be liable for any damage or loss resulting from fire, flood or accident that may occur on or in connection with the works during their progress.

Progress of Works.

22. That it shall be lawful for the Engineer to call upon the Contractor by notice in writing to engage within..................

such additional workmen and plant of any description as the Engineer may consider necessary to push forward the works sufficiently.

Clearing Up.

23. All debris and rubbish is to be cleared up, and removed or destroyed on completion of the work.

Subletting or Assignment.

24. The Contractor must not sublet any portion of the works or enter into any subcontract for the execution thereof or assign any deposit moneys or any moneys payable or that may become payable under the contract without the consent of the Engineer, under his hand in writing. And no such subletting, subcontract or assignment without such consent shall be recognised by the [Proprietor], and the same shall be void to all intents and purposes.

Works to be Completed under Penalty.

25. The works included in the contract shall be completely finished and delivered up to the [Proprietor] on or before................................ and for each and every day's delay in the completion of the works after the day stipulated he shall be entitled to deduct from any deposit or moneys then due or that may become due the sum of (£..............) for each day during which the works may remain unfinished beyond such period, unless the works shall have been suspended by the Engineer for some cause not arising from any default of the Contractor, in which case further time will be allowed for the completion of the contract equal to the delay caused by such suspension.

Arbitration.

26. In case any dispute or question shall arise between the [Proprietor] and the Contractor touching the construction of the Contract Condition or Specifications, or any of them, or touching the mode in which the Contractor is carrying out or has carried out his contract, or touching any other matter or thing in any way arising out of or relating to the Contract Conditions or Specification, or any of them. then the [Proprietor] and the Contractor shall enter into a written agreement to submit such dispute or question to the award or determination of some arbitrator to be appointed jointly by the [Proprietor] and Contractor and to be named in such agreement; or if they shall not be able to agree upon the appointment of a single arbitrator, then of two arbitrators to be named in such agreement, to be appointed, one by the [Proprietor] and the other by the Contractor; and of a third arbitrator to be appointed by such other two arbitrators, or of any two of such three arbitrators, and such agreement or submission to contain provisions for its being made a rule of the Supreme Court, and that the award shall be made within fourteen days from the date of such agreement, unless the arbitrator or arbitrators shall by any writing signed by him or them, endorsed on the submission, enlarge the time for making the award; and that the costs of the submission and award and incidental thereto shall be in the discretion of the arbitrator or arbitrators, who may direct to and by whom and in what manner the same or any part thereof shall be paid. If in the event of the [Proprietor] and Contractor not agreeing upon the appointment of a single arbitrator, either of

them shall neglect for one week after being required in writing so to do to appoint an arbitrator, then the other party shall appoint an arbitrator for him, and the two arbitrators shall appoint a third arbitrator. If either the [Proprietor] or Contractor shall not, on being called on to do so, execute such agreement or submission, or if either shall, pending such arbitration, commence any action, suit or other legal proceeding, touching any dispute or question which shall have been referred to arbitration, he shall pay to the other party the sum of........................(£), by way of liquidated damages, but neither party shall be entitled to call on the other to execute any such agreement except within................days after the dispute or question shall have arisen.

Bankruptcy and Cancellation of Contract.

27. If the Contractor shall become bankrupt or insolvent, or if in the opinion of the Engineer the Contractor shall fail to make such progress with the works as is necessary to insure their completion within the above specified time, or if in the opinion of the Engineer the Contractor shall use bad or insufficient materials, or execute the work in an unsound or imperfect manner, and should in either case neglect or fail to make good the same or to rectify any complaint of the Engineer when required so to do, then after three days' notice to that effect from the Engineer it shall be lawful for the [Proprietor] to employ additional men, horses, materials or plant of any kind at the Contractor's expense; or, if deemed more expedient, the [Proprietor] shall have power to cancel the contract, and to take the work out of the Contractor's hands, and to enter into any other contract or such other arrangements for the completion of the works as he may think necessary, and to retain as by way of ascertained and liquidated damages for breach of contract all moneys in his hands that may then be due or thereafter become due to the Contractor.

Deposit Security.

28. That the amount deposited by the Contractor as security for the due performance of the contract shall be held by the [Proprietor] until the Engineer certifies that the contract is completed to his satisfaction, but should the Engineer be of opinion that the Contractor has failed to perform any of the obligations of the contract, or to complete it within the stipulated time, the [Proprietor] shall be entitled to declare forfeited the whole or any portion he may think fit of the amount so deposited as a security, and the same shall thereupon become and be absolutely forfeited as liquidated damages. The [Proprietor] may, previous to the completion of the contract, return to the Contractor the whole or any portion of such deposit, but such return thereof shall not waive, prejudice, release or discharge any of the conditions or obligations of the contract whatever.

Interpretation Clause.

29. In the construction of these Conditions the singular number of the following words, viz., [Proprietor] and Contractor shall, where necessary, be taken to include the plural; and the word [Proprietor] shall mean the person entering into the agreement with the Contractor. The word Engineer shall mean.........................

332. Contract Agreement.—Municipalities and public companies generally possess printed forms of deed. The following is suitable for general use:—

SCHEDULE OF RATES CONTRACT.

THIS CONTRACT, made the............day of.............. in the year of our Lord One thousand nine hundred and ...., Between...hereinafter and in the Documents annexed hereto called "the Contractor" of the first part and....................................hereinafter and in the said Documents called ["the Proprietor"] of the second part—

WITNESSETH that the Contractor for himself his heirs and administrators hereby covenants with the [Proprietor] to execute and perform the several works and provisions and supply and materials and labour and everything of every kind respectively named shown and described and referred to in the Specification Conditions of Contract and Schedule of Quantities and Rates hereto respectively annexed to be executed and supplied by and on the part of the Contractor in conformity with the said specification and under and subject to the Conditions of Contract also hereto annexed at the rates set out in the said Schedule of Quantities and Rates. AND the Contractor for himself his heirs executors and administrators hereby covenants with the [Proprietor] and the [Proprietor] hereby covenants with the Contractor to perform fulfil observe and comply with and submit to all and singular the conditions stipulations and requisitions and all matters and things contained expressed and shown in or reasonably to be inferred from the said Specification Conditions of Contract Schedule of Quantities and Rates and by and on the part of the Contractor and the [Proprietor] respectively to be performed fulfilled and observed. AND it is also mutually covenanted that if the party hereto of this first part shall consist of two or more persons the term "the Contractor" herein and in the Documents annexed hereto shall bind such persons jointly and severally and their respective heirs executors and administrators, and such persons shall jointly be entitled to the benefit of this contract and these presents and the said Documents shall be read and construed accordingly.

Signed sealed and delivered by the above named

....

....

in the presence of

....

and by the above named

....

....

in the presence of

....

SCHEDULE OF DOCUMENTS ANNEXED TO WHICH ABOVE CONTRACT REFERS.

1. Specification. 2. Conditions of Contract. 3. Schedule of Quantities and Rates.

333. **The Schedule.**—The use of the schedule is to summarise the work to be done, and on it to set forth the rates to be paid to the contractor. The schedule and specification are read together, and must not conflict. The specification should as far as possible be complete in itself, but in a general specification, it is allowable to refer to the schedule for details of classification. Under clause 2 of Conditions of Tendering each tenderer must send in his schedule precisely in the form given in the contract papers. This rule should be rigidly insisted upon, and any irregular attempt on the part of contractors to ignore it promptly suppressed. Specimen schedules will be found scattered throughout this book.

334. **The Specification.**—The specification, of which numerous examples are given in preceding chapters, should be a clearly-worded description of the work to be done, of the materials to be used, and of the class of workmanship and methods to be employed; it must also define the classification under which the work is to be paid for. Legal phraseology should not be attempted, and the document should be drawn up in simple language intelligible to any contractor, and in which there can be no doubt as to the intention of the engineer.

Before drafting a specification it is always advisable, more especially for inexperienced engineers, to epitomise the various points, and then to work under headings. If this is done there will be much less chance of omitting details, and the document will be clearer and more distinct. In specifying it is necessary to keep in mind the possibility that one or both parties to the contract may possibly prove unscrupulous, and may desire to take unfair advantage of any flaw or ambiguity. Remember that the engineer should at all times occupy an independent position, and should not act as a partisan for his employer. His specifications should be drawn so that neither can take unfair advantage of the other. He should critically revise them from every point of view, and remove every loophole or ambiguity that may present itself.

Specifications must, above all, be explicit and precise, so that the contractor may know exactly what he is tendering for, and must not leave a great deal to the discretion of the engineer. The use of the words "or as directed by the engineer" should be used as sparingly as possible. How can tenderers possibly know what is in the engineer's mind, and to what extent his variations may involve them?

Some specifications are so vague as to make one wonder why contractors will work under them. With such a clause as "all cement is to be subject to such tests as the engineer may decide, and his decision in the matter shall be final," how can satisfactory competition be secured? The engineer, in effect, reserves to himself the right to ruin the contractor by prescribing impracticable tests should he so desire.

In road-making specifications one sometimes reads, that the road is to be rolled so many traverses with a roller of a certain weight, without stating whether a steam or horse roller is to be used. Such ambiguity is to be avoided. It is a great mistake to blindly copy specifications without full inquiry as to their suitability for the proposed work and conditions.

335. **Drawings.**—In letting contracts for road works, or indeed for engineering works of any description, it is very important that the drawings, which illustrate the schedule, specification, &c., should be accurate, clear, and ample. Indeed they may be considered part of the specification, and if they are drawn to a sufficiently large scale a good deal of descriptive matter can be advantageously shown on them. See §§ 58, 71, and 307. First of all there should be a clear and well-plotted *Locality Plan* showing the site of the work, all important features, the various distances, the positions, numbers, and heights of the pegs, and in fact all the information necessary to enable a prospective tenderer to understand clearly the limits of the different cuts and fills and the situa-

tions of the structures, such as bridges, culverts, kerbs, &c. In making the survey for any work, the engineer would, of course, obtain all the information necessary for its accurate design and for the calculation of quantities, and he should put this information on his contract drawings, the labour involved being trifling, provided his field notes are well and clearly kept.

The Longitudinal Section, or profile, should be drawn to a considerably exaggerated vertical scale, and should show very clearly cuts, fills, and surface formations. The distances should correspond with those given on the locality plan, and it should be easy to connect the cross sections with the profiles, so that the quantities of cutting and banking may be conveniently determined.

The Cross Sections should be drawn to such a scale that their areas may be correctly enough ascertained by the use of the planimeter, and they should be at sufficiently close intervals to allow of the quantities being accurately taken out. In large works the earthwork quantities are often checked by the contractor's engineer as the work proceeds, but in smaller jobs it is convenient to take them out carefully before scheduling the items, and to specify that the contractor must satisfy himself as to their accuracy before tendering, and, if successful, must accept them as being correct. In small works there must obviously be a limit to the amount of measuring up, or the cost of measurement will be out of all proportion to the value of the job.

Drawings of Structures should be clear and accurate, and to avoid misconceptions should contain as much description of parts as is practicable without so crowding the plans as to make them hard to read. It need scarcely be said that all drawings should be made before the specifications are written, and that the greatest care must be taken not to make either conflict with the other. Distinctive colouring adds greatly to the clearness of drawings, but it is not always advisable to colour. In even country, such as is common in many parts of Australia and of the Dominion of New Zealand, type drawings may be lithographed or blue-printed with great saving of time and labour, and without detriment to the efficiency of the works. In large contracts, again, it may be considered advisable to circulate the contract papers pretty widely, and in such cases the drawings should be in black and white for cheap and easy reproduction. Engineers carrying out small road works often experience great trouble from the misreading of plans and specifications by contractors, unable at once to understand those documents, and unwilling to go to the expense of getting proper copies that they should digest at their leisure. In all cases the contractors could be in possession of complete copies of the contract papers, so that mistakes may be avoided as far as possible, and they should be compelled to keep these always on their jobs for reference. See §§ 69 and 330. In conclusion, it may be said that there is little use in going to the trouble of carefully setting out and designing road or other works unless strict adherence to plans and specifications is insisted on, and the young engineer should take care in all his doings to be firm as well as fair.

INDEX.

A.

Abrasion by wheels, 191.
Administration of municipal affairs, 32.
Afflux at bridges and culverts, 282, 283.
Agricultural drain pipes, use, cost, 78.
Aitken's tar-spraying machine, 206, 207.
Analysis of tar, 204.
Aneroid barometer, correction co-efficients, 51.
  method of using, 50-52.
  size useful, 50.
Annuity. present value of, 17.
Artificial asphalt, 218.
Asphalt macadam, 216.
  cost, 217.
Asphaltum for footways, cost of, 269.
  mastic, 269.
  Trinidad, 269.
Asphaltum for roads, artificial, 218.
  binder or cushion coat, 219.
  composition blocks, 220.
  cost of, 221.
  foundation for, 218.
  gradients suitable on, 221, 225.
  laying of, 218.
  life of, 225.
  maintenance of, 223.
  mastic, 218.
  materials and methods compared, 222.
  natural rock, 217.
  paving in Auckland, 221, 222.
  rolling of, 218.
  Trinidad, 219.
  Val-de-Travers, 217, 218.
  wear of, 221.
  wearing coat, 220.
Attrition test of road metal, 129-131.
Auckland, paving in Queen-st., 221, 222.
Axle, friction, 1.
Axles, effect of equal, 192.

B.

Balancing earthwork, 65.
  in town work, 162.
Barometer (see aneroid).
Barrow and plank work, cost, 69.
Basalt, 126.
  cost of metal, 150, 151.
  cost of quarrying, 138-140.
  distribution of, 127.
  flagstones, 268.
  pavement, life of, 225.
Benefits from good roads, 9, 11. 12.
Binding, application of, 180.
  cost of, 186.
  gravelled roads, 101.
  material, 178, 179.
  metalled roads, 155, 176.
  necessity for, 155, 176.
  quantity of, 179.
  specification for, 183.
  when road ravelling, 198.
Bins for crushing plants, 148.
Bithulithic pavement, 215.
  cost, 216.
Bituminous cement. 215.
Blackbutt woodblocks, 228.
Blasting, gelatine. 135.
  in quarries, 132 to 137.
  in road works, 304.
  machines, 137.
Blinding (see binding).
Bluegum wood blocks, 228.
Bluestone (see basalt).
Bomford and Marshall's scarifier, 119.
Bonding of metalled roads, between old and new, 196, 197.
  chemical, 178.
  mechanical, 177.
  water, 177.
Boreholes. 133, 134.
  cost, 134.
Box, for wood blocks, 228.
Breaking metal, cost of, 149 to 151.
  hand v. machine, 140.
Breaking through of metalled roads, 191.
Breaking up old road surfaces, 117-121, 196.
Bricks, laying of, 249.
  quality of, 248.
Brick drains, 292.
Brick pavement—for roads, American practice, 248.
  cost, 251.
  gradients suitable, 225.
  grouting of, 249, 250.
  laying of. 249, 268.
  life of, 225.
  quality of bricks, 248.
  —for footways, cost, 268.
Brick sewers, 283.
Bridges—afflux at, 282, 283.
  cost, comparison of, 17-19.
  economics, 17-19.
  highway 43, 290, 291, 305.
  selection of sites, 53, 54.
  timber v. steel, 17-19.
Brooms, scavengers', 202.
Burnt clay roads, construction, 85.
  cost, 86.

C.

- Cableways, use in quarries, 131.
- Cainks' jets and sprinklers, 201.
- Caithness flagstones, 268.
- Carting and dumping, cost, &c., 10, 11, 69, 185.
- Cast iron, gullies, 296.
  - kerbs, 263.
- Castlemaine flagstones, cost, 269.
- Cement. specification and tests, 234.
- Cement flags, 267.
  - cost, 267.
- Cement pavements, 266.
  - cost, 267.
- Chamier's run-off formulae, 275-278.
- Channels on roads, 82, 83.
- Channelling, pitched, cost, 187.
  - laying, 291.
- Chezy formula for discharge, 273.
- City pavement economics, 19-21.
- Clay, as binding material, 179.
- Clay footpaths, improvement, 260.
- Clay roads, burnt, 85.
  - cost of burnt, 86.
  - drainage of, 84.
  - foundations, 157, 158.
  - sanding of, 84, 85.
- Cleansing of town streets, 199-203.
- Clearing, effect on run-off, 275.
- Clearing of roads, 76.
  - cost, 89.
  - specifications, 87, 88, 103.
- Cliffs, roads on faces of, 304.
- Climate, effect on roads, 189, 190.
- Clinker for concrete flags, 267.
- Clinometer, for road grading, 49, 50.
- Collisions, resistance due to, 2.
- Compression of metal under rolling, 171.
- Concrete, gutters, 292.
  - kerbs, 262.
  - pipes, 283, 284.
  - reinforced bridge, 43.
  - reinforced covers, 286.
  - reinforced gullies, 297.
- Concrete foundation, for asphaltum, 218.
  - for brick pavement, 249.
  - for stone pavement, 243.
  - for wood blocking, 229.
  - specification for, 237.
- Concrete, roads, cross section, 240.
  - gradients suitable, 225.
  - laying, 240.
- Conditions of contract, example of, 311-320.
- Conditions of tendering, example of, 309-311.
- Contour ditches, 271, 272.
- Contracts, agreement form, 321.
  - conditions of tendering, 309-311.
  - contract v. day labour, 29-31.
  - cost plus fixed sum, 307.
  - cost plus percentage, 307.
  - different kinds, 307.
  - documents, 308-325.
  - drawings, 323-325.
  - form of tender, 308.
  - general conditions, 311-320.
  - lump sum, 307.
  - schedule for, 322.
  - schedule of rates, 307.
  - specification, 322, 323.
- **Cost** (see the item in question).
- Country roads, cost data, 68-70, 89, 90.
  - cross sections of, 79-83, 99, 160, 161, 300-304.
  - drainage of, 271.
  - trimming of flanks, 198.
  - width of metal, 161, 162.
- Creek crossings, selection of, 53, 54.
- Crown, for metalled road, 158, 159.
  - for paved roads, 230, 231.
- Crossing places, choosing, 53, 54.
- Crossings over gutters, 293, 294.
- Cross communication, preservation of, 39.
- Cross sections, city streets, 167, 168, 231, 240.
  - earth roads, 79-83.
  - gravelled roads, 99.
  - metalled roads, 160, 161, 163-176.
  - mountain roads, 300-304.
  - paved streets, 230.
  - on side-long ground, 165-169, 300-304.
  - suburban streets, 163-169.
  - town streets, 163-169.
- Crushers, bins for, 148.
  - cost of, 148, 149.
  - cost of working, 149, 150.
  - jaw, 144, 145.
  - portable, 148.
  - rotary, 145, 146.
  - screening, 146-148.
  - stationary, 142-144.
  - types, choice of, 141.
- Crushing, cost of, 149-151.
- Cuppy roads, 173, 213.
- Culverts, afflux at, 282, 283.
  - covers for, 286.
  - discharge of pipe, 281, 282.
  - masonry, 284.
  - over gutters, 293, 294.
  - pipe, 279-281.
  - specification, 89.
  - timber, 286-289.
- Curves on mountain roads, 56, 299.
  - vertical, at grade intersections 299.
- Curved section for metalled roads, 160.
- Cushion coat for asphaltum, 219.
- Cuttings, rock, 303, 304.
  - safe slopes for, 63, 64.
  - side-long, 301-304.

D.

- Day labour, compared with contract, 29-31.
- Depth of metal, 168-171.
  - formula for, 171.
  - for maintenance, 198.
- Detonators, cost, use, 136.
- Deviation of roads, 41, 42.
- Diabase, 125.
  - attrition tests, 130.
  - cost of metal, 150.
- Differential gear for rollers, 113.
- Discharge of drains, calculation, 273.
  - pipe culverts, 281, 282.
  - tables for, 278.
- Distance, value of saving, 42, 43.
- Distillation of tar, 205.

- Drains, agricultural, cost, use, 78.
  - brick, 292.
  - concrete, 293.
  - discharge of, 273.
  - fall allowable, 274.
  - grading on steep roads, 274.
  - pitched, 291.
  - subsoil, 78, 104.
  - surface, 81-83.
  - wood-paved, 292.
- Drainage, country roads, 271.
  - earth roads, 77, 78.
  - method of treating, mountain roads, 301.
  - necessity for, 157.
  - obligations of municipalities, 270.
  - specification for, 104.
  - surface, 81-83.
  - watertables, 81.
- Drawings, preparation of, 323-325.
- Drilling, cost, 134.
  - hand, 133.
  - machine, 134.
- Drought, effect on roads, 190.
- Drying of metal, 210.
- Dust prevention, general principles, 253-255.
  - necessity for, 252.
  - oiling, 257.
  - palliatives, 255.
  - points for attention, 258, 259.
  - tarring, 257-258.
  - watering, 255-257.
- Dynamite, 135.
  - quantity required, 137.

E.

- Earth, classification of, 61.
  - loosening methods, cost, 67, 68.
- Earth roads, cost, 89, 90.
  - channels on, 83.
  - clearing, 76.
  - compared with metal, 13, 14.
  - construction of, 82.
  - cost of scraping, 92.
  - cross sections, 79-81.
  - general considerations, 76, 77.
  - improvement of, 84.
  - loaming of, 82.
  - maintenance of, 90-92.
  - necessity for good design, 76.
  - oiling, 94, 95.
  - re-formation, 84.
  - scraper for, 92.
  - specification, 87-89.
  - split log, drag for, 91.
  - sub-drainage, 77, 78.
  - water-breaks, 83.
  - watertables, 81, 82.
- Earthwork, balancing, 65.
  - barrow and plank, 69.
  - batter allowable, 63, 64.
  - carting and dumping, 69.
  - classes of, 61.
  - costs, 67-73.
  - cost in town streets, 187.
  - embankments, safe slopes, 64.
  - loosening methods, cost, 67-73.
  - measurement, 67.
  - payment methods, 66, 67.
  - road machines, 71-73.
  - scooping, 69-71.
  - shrinkage of, 61-63.
  - slopes allowable, 63, 64.
- Economics, benefits of good roads, 7-9.
  - bridge, 17-19.
  - comparison, good and bad roads, 11-13.
  - metalled and earth roads, 13-14.
  - contract and day labour, 29-31.
  - cost data necessary, 9, 10.
  - good advice, 32.
  - gradients, 15.
  - pavements, 19-21.
  - permanent works, 15.
  - steel wheelways, 21, 22.
  - temporary works, 15.
  - tramways in forests, 24.
  - width of tires, 27-29.
- Electric, exploders, 137.
- Electric tramways, 22, 23.
- Elevating graders, 73.
- Embankments, construction, 64.
  - safe slopes, 64.
  - swampy ground, 65.
- Engineers, consulting, 32.
  - salaries, 32.
- Entry head, 281.
- Erosion of drains, 271.
  - arresting of, 271, 272, 274.
- Estimates contractor's profit, 31.
  - local conditions, 31.
  - necessity for, 30.
  - wages rates, 31.
- Excavation (see earthwork).
- Expansion joints for wood paving, 232.
  - specification, 238.
- Explosives, blasting gelatine, 135.
  - blasting machines, 137.
  - choice of, 134, 136.
  - costs, 136.
  - detonators, 136.
  - dynamite, 135.
  - electric exploders, 137.
  - gelignite, 135.
  - quantity required, 137.
  - rackarock, 135.
  - roburite, 135.
  - use of, 136.
  - use in road works, 304.

F.

- Fall allowable in drains, 274.
- Fencing, on mountain roads, 302.
  - on roads, 92.
  - specification, 93, 94.
- Finance of road works, 7-24.
- Flagstones, 268.
  - cost, 269.
- Flanks, trimming of, 198.
- Flat country, road location, 39.
- Flexible wheels for traction engines, 192.
- Flint, 129.
  - attrition tests, 130.
  - for tar macadam, 209.
- Footbridges, 293, 294.
- Footways, brick, 268.
  - cement flags, 267.
  - cement matrix, 266.
  - earth, 260.
  - gravel, 260.
  - stone flags, 268.
  - tar-paved, 264-266.
  - width of, 163, 260.
- Forest country, tram lines in, 24.

Formation of roads, cost, 89, 90.
  specifications, 88, 89, 103, 104.
Foundations, for asphaltum, 218, 269.
  for brick pavement, 229, 268.
  costs, 184, 185.
  for metalled roads, 152-158, 167.
  for stone pavement, 243.
  for wood blocking, 229.
Fowler's steam rollers, 109.
French roads, early, 170.
  example of, 304.
  policy adopted, 33, 34.
Friction, axle, 1.
  rolling, 2.
Frost, effect on roads, 190.
Fuses, cost, 136.
  use, 136.

G.

Garbage carts, 202.
Gauge, of gravel, 96.
  of metal, 171, 197.
Gelignite, 135.
  quantity required, 137.
General conditions of contract, 311-320.
Graders, elevating, cost, 73.
  operation, 73.
Gradients, deciding on, 54, 55.
  economy of, easy, 15.
  effect on haulage, 44.
  financial aspect, 45, 46.
  maximum for cities, 47.
  maximum for pavements, 225.
  minimum, 39.
  resistance due to, 4.
  ruling, 45, 46.
  steep streets, 47.
  uniform, 55.
Grading of roads, examples, 55-58.
  final survey, 60.
  reconnaissance, 48-50.
  spirals, 59.
  steep ascents, 298.
  tacheometer for, 59.
  trial survey 57.
  Victorian system, 42.
  zig-zags, undesirable, 58.
Grading of watertables, 273, 274.
Granite, 124.
  attrition tests, 130.
  durability of. 225.
  metamorphic, 127.
Gravel, compression of, 100.
  cost, 106, 107.
  description of, 96.
  for footpaths, 260.
  Mangalore, 97.
  measurement, 101, 102.
  pit, 97.
  qualities of, 96, 97.
  quantities, table of, 102.
  river, 97.
  screening, 97.
  Silurian, 97.
  specification, 104.
  spreading, 100.
  thickness, 99.
  weight, 98.
  width, 99.
Gravelled roads, binding, 101.
  cost, 106.
  cost of maintenance, 107.
  cross sections, 99.
  foundation, 98-100.
  maintenance, 107.
  rolling, 100.
  sandy foundation, 100.
  specification, 103-105.
  spreading, 100.
  thickness, 99.
  width, 99.
Grippers on traction engines, 192.
Grouting, brick pavement, 249, 250, 268.
  pitched drains, 291.
  specification, 247.
  stone pavement, 244.
Gully traps, 294.
  cast iron, 296.
  reinforced concrete, 297.
  Stone's patent, 296.
Gutter crossings, 293.

H.

Hand-breaking metal, 140, 141.
  disadvantages, 140.
Haulage, comparisons for different grades, 46.
  cost, 10, 11, 44.
  effect of grades, 44.
Heavy traffic, steel wheelways, 21, 22, 250, 251.
Hogg's road paring machine, 198.
Horses, effect of feet on road, 190.
  power of, 5, 6.
  specification for supply of, 73-75.
Horse rollers, 116, 117.
Hydraulics, 272-283.

I. and J.

Improvements, clay roads, 84, 85.
  financial aspect, 9.
  how to secure, 32, 33.
  permanent, 15-19.
  sandy roads, 86, 87, 245.
  temporary, 15-19.
Iron gullies, 296.
Iron kerbs, 263.
Jarrah, wood blocks, 228.
Jaw crushers, 144.
Journal friction, coefficient, 1.

K.

Karri wood blocks, 228.
Kauri wood blocks, 228.
Kerbing, cast iron, 263.
  concrete, 262.
  cost, 187, 262.
  dimensions, 261.
  specification, 261, 262.
  wooden, 263.
Kernot formula for bridge openings, 275.
Khleinpflaster, cost, 242.
  use, 241.

L.

Labour, wages payable, 29-31.
Levels of streets, fixing, 162.
Life of pavements, 225, 232.
Limestone, 128.
  attrition tests, 130.
  for tar macadam, 128, 209.
  screenings as a binder, 178.
Loads hauled by a horse, formula, 5.
  table, 6.

Loaming earth roads, 82.
  specification, 88.
Location of roads, cost justified, 39.
  curves allowable. 56.
  deciding on grade. 54.
  directness of route, 42, 43.
  early practice, 38.
  final survey, 60.
  flat country, 39.
  grades, 55.
  grading between saddles, 55.
  grading uniformly, 54.
  importance of, 38.
  instruments used, 49.
  mountainous country, 53.
  reconnaissance, 48, 49.
  river crossings, 53.
  sandhill country, 52.
  trial survey, 57.
  valley roads, 52.
  undulating country, 53.
  vested interests, 47.
Loosening earth, cost, methods, 67, 68.

M.

Macadam, cost compared with wood blocking. 19-21.
  modern, 154, 170.
  thickness of, 171 (see also metalled roads).
Machinery, modern, combined ownership, 33.
  necessity for, 33.
Machines road, cost, use, 71-73.
Mahogany wood blocks, 228.
Main roads, nationalisation of, 33.
  policies in other countries, 33-36.
Maintenance, asphaltum, 223.
  contract system, 203.
  climate, effect of, 189.
  cost for earth, 92.
  cost for gravel, 107.
  cost for metal, 203, 208.
  gravelled roads, 107.
  patching v. sheeting, 194-196.
  season for repairs, 196.
  skill necessary, 189.
  specifications, 105, 184.
  traffic. effect of, 190.
  traffic, volume of, 193.
  systems, 194.
  tar macadam, 214.
Marshall's steam rollers, 110.
Masonry culverts, 284.
Mastic, for wood paving, 232.
Mastic asphalt, cost, 269.
  for footpaths, 269.
  for roads, 218.
Maximum gradients (see gradients).
Measurement of earthwork, 67.
  of gravel, 101, 102.
  of metal, 173.
  table of quantities, 102.
Metal, attrition tests, 129-131.
  basalt, 126.
  cementing power, 123.
  characteristics and distribution 124.
  compression under rolling, 171.
  costs, 140, 141.
  cost of breaking, 149-151.
  crushers (see crushers).
  diabase, 125.
  drying, 210.
  economy of hard, 126.
  flint, 129.
  gauge, 171, 197.
  granite, 124.
  hand-breaking, 140, 141.
  hardness, 122.
  limestones, 128.
  measurement, 173, 182.
  metamorphic granite, 127.
  porphyries, 125.
  power to obtain, 122.
  qualifications of suitable, 122-124.
  quantity required, 194.
  quarrying (see quarrying).
  quartzite, 128.
  sandstone, 128.
  schists, 127.
  screening, 146, 148, 172.
  shales and slates, 128.
  specification, 182.
  spreading, 173, 183, 198.
  testing (see tests).
  thickness of, 168-171, 198.
  toughness, 123.
  volume produced, 138.
Metalled roads, bad v. good, 11-13.
  binding of, 176, 179, 180.
  bonding of, 177, 178.
  breaking up, 196.
  choice of methods, 155, 156.
  city streets, 167, 168.
  cost compared with earth, 13, 14.
  cost of rock bottom, 185.
  cost of rolling, 186.
  cost of spreading, 185.
  cost of street construction, 187.
  cost of Telford, 184.
  country, 160, 161.
  cross sections, 160-171.
  crown, 158, 159.
  curved section, 160.
  foundations for, 156-158.
  Macadam's method, 152.
  maintenance (see maintenance).
  modern macadam, 154.
  mountain, 305.
  ravelling, 198.
  rock bottom, 153.
  rock foundation, 158.
  rolling, 174-176.
  side-long ground, 165-169.
  specification, 180-184.
  straight line section, 160.
  suitability of, 152.
  tarring surface (see tarring).
  Telford pavement, 152, 153.
  town and suburban, 163-165.
  transverse profile, 160.
  wear of, 193.
Metamorphic rocks, 127.
Morrison's scarifiers, 120.
Motor cars, on roads, 192.
  for dust, 253.
Motor rollers (see rollers).
Motor track, 165-167.
Motor water vans, 200.
Mountain roads, bridges on, 305.
  cost, 306.
  cross sections, 300-304.
  curvature, 299.
  drainage, 301.
  location of, 53-58.
  passing places, 299.
  vertical faces, 304.
  width, 59, 300.

N.

Natural rock asphalt, 217.

O.

Odometer, in road location, 50.
Oil, class required, 94.
  crude. 257.
  saponified, 257.
Oiling earth roads, 94, 95.
  Californian practice, 95.
  cost 95.
Oiling metalled roads, 257.
  cost, 257.

P.

Parapet walls, mountain roads, 303.
Passing places, mountain roads, 299.
Patching v. sheeting. 194-196.
Pavements, city economics, 19-21.
  comparison of different, 224.
  cross sections, 230, 231, 240.
  crown for, 230.
  durability, 225.
  life. 225.
  maximum gradients for, 225.
  transverse profile, 231 (see also asphaltum, brick, stone, wood pavements).
Permanent v. temporary works, 15-19.
Pick and shovel work, cost, &c., 68.
Picking road surfaces, cost, 121.
  not effective, 197.
Picking up sweepings, 201, 202.
Pipes, cost of laying stoneware, 279.
  cost of stoneware, 279.
  crossings, 293.
  culverts, 279-281.
  discharge of, 278.
  discharge of culverts, 281, 282.
  reinforced concrete, 283, 284.
  tables for discharge, 279.
  weights of stoneware, 279.
Pitch, 204.
Pitched drains, cost, 187.
  examples, 291.
Pitchers, cost, 245.
  durability, 246.
  size, 243, 291.
  specification, 246.
  wear, 246.
Plans, preparation of. 323-325.
Ploughs and ploughing, cost, &c., 67, 68.
  for breaking up roads, 197.
Policy in foreign countries, 33-36.
Porcupine scarifier, 118.
Porphyries, 125.
  attrition tests, 130.
Portable crushers, 148.
Portland cement, 234 (see cement).
Power of a horse, 5, 6.
Present value of an annuity, 17.

Q.

Quarrying, bore holes, spacing of, 133.
  cable way, 131.
  choice of quarry site, 131.
  costs, 138-140.
  cost of bore holes, 134.
  drilling by hand, 133.
  drilling by machines, 134.
  explosives (see explosives).
  methods, 131, 132.
Quartzite, 128.
  attrition tests, 130.

R.

Rackarock, 135.
Rails as culvert stringers, 290.
Rainfall curve of storm intensities, 276.
  effect on roads, 190.
Ravelling of roads, 198.
Reconstruction of roads, 83, 84.
Redgum wood blocks, 228.
Re-formation, 84.
  specification, 182.
Reinforced concrete, covers for culverts, 286.
  gullies, 297.
  pipes, 283, 284.
Renewal fund, policy of, 19.
  table for, 16.
Resistance to traction, collisions, 2.
  gradient, 4.
  on level, 3.
  rolling resistance, 2.
Retaining walls, 303.
Rights-of-way, necessity for, 40.
  width, 40.
River and creek crossings, 53, 54.
Road banks in swampy ground, 65.
Road economics, 7-37.
Road improvements, finance of, 9.
Road machines, cost of, 73.
  cost of operation, 72, 73.
  operation of, 71, 72.
  specification for working, 74.
Roburite, 135.
Rock bottom roads, 153.
  advantages, 156.
  cost, 185.
Rock foundation, 158.
Roller carts, 101.
Rollers, horse, 116, 117.
Rollers, motor, advantages, 116.
  American sizes and weights, 116.
  cost of English, 115.
  size and weights, 115.
Rollers, steam, Australian-made, 110.
  compound cylinder 109.
  construction details, 110-113.
  conversion to traction engine, 109.
  differential gear. 113.
  dimensions, 109, 110.
  gradients, safe, 108.
  horizontal boilers, 108.
  machinery driving, 109.
  scarifiers for, 112.
  single cylinder, 109.
  spikes for, 117, 197.
  spring mountings for, 115.
  vertical boilers, 108.
  weights, 109, 110, 175, 176.
Rolling asphaltum, 218.
  before binding, 180.
  by municipality, 175.
  cost of horse, 186.
  cost of steam, 186.
  gravelled roads, 100.
  metalled roads, 174.
  necessity for, 155.
  specification, 88, 105, 183.
  sub-grade, 99.
  tar macadam, 211.
Rolling friction, 2.

Roman road, 170.
Rosewater formula for crown, 230.
Rotary crushers, 145, 146.
Rugosity, coefficient of, 273, 278.
    for pipes, 278.
    for reinforced concrete pipes, 284.
Run-off from storms, 274-278.
    Chamier's method, 275-278.
    Kernot's formula, 275.
    percentage of run-off, 275-277.
Rutting of metalled roads, 191.
Rutty scarifier, 118.

S.

Saline solutions, 256.
Sand, as a binder, 176.
    bedding for pavements, 243.
    foundation for metal, 100, 158.
    specification for, 235.
Sandy roads, gravel on, 100.
    improvement, 86, 87.
    location, 52.
    marram grass on, 87.
    stone pavement for, 245.
    wood pavement for, 245.
Sandstone, 128.
    attrition tests, 130.
    flags, 269.
Saponified oil mixtures, 257.
Sawn basalt flagstones, 268.
Scarifiers, 117-121.
    Bomford and Marshall's, 119.
    Henderson's, 118.
    Morrison's, 120.
    Rutty's, 118.
Scarifying, cost, 120.
    comparison with hand-picking, 121.
    necessity for, 197.
Scoops, drag, 69, 70.
    wheeled, 70, 71.
Scooping, cost, 70, 71.
Scrapers, for earth roads, 90-92.
Scraping, cost for earth roads, 92.
    machines, 202.
Screening, gravel, 97.
    metal 146-148.
    necessity for, 172.
Screenings, as binders, 178, 179.
    volume produced, 138.
Sea walls, 187, 188.
Sea water for streets, 256.
Season, caution, preface.
    for earth road repairs, 91-92.
    for road repairs, 196.
    for tarring, 196.
    for trimming, 198.
Sedimentary rocks, 128.
Sets, size, 243.
    specification, 246.
Sewers, brick, 283.
Sewerage, effect on street location, 40, 41.
Shales, 128.
Sheeting v. patching, 194-196.
Shone system for sewage, 41.
Shot holes, 133, 134.
    cost, 134.
Shrinkage of earth, 61-63.
Side slopes, 63, 64.
Side-long ground, cross sections on, 165-169, 301-304.
Silurian gravel, 97.
Sinking fund, table for, 16.
Sites for bridges, 53, 54.
Size, of metal, 171, 197.
    of wheels, 2.
Slates, 128.
Slipperiness of wood pavement, 232.
Specifications, drafting of, 322, 323.
Specification, binding, 183.
    cement, 234.
    clearing, 87-89, 103.
    concrete, 237.
    fencing, 93-94.
    formation, 87-89, 103.
    gravelled roads, 103-105.
    horses and carts, supply of, 73-75.
    kerbing, 261, 262.
    maintenance, 105, 184.
    metal, 182.
    metalled roads, 180-184.
    rolling, 88, 105, 183.
    stone pavement, 246, 247.
    subsoil drains, 104.
    tar pavement, 264, 265.
    wood blocking, 234-239.
Spikes for steam rollers, 117, 197.
Split-log drag, 91.
Spreading of gravel, 100.
Spreading of metal, 173, 198.
    cost, 185.
    specification, 183.
Spreading of tar macadam, 211.
Sprinklers for water carts, 201.
Stationary crushing plant, 144.
Steam rollers (see rollers, steam).
Steel rail stringers for culverts, 290.
Steel wheelways, construction, 250.
    cost, 251.
    economy, 22.
Steep streets, table of, 47.
Stock routes, 40.
Stone (see metal).
Stone's gully traps, 297.
Stone-breakers (see crushers).
Stone pavement, cost, 245.
    cross section, 243.
    durability of, 246.
    foundation for, 243.
    gradients suitable, 225.
    grouting of, 244.
    laying of, 244.
    life of, 225.
    sandy ground, 245.
    size of stones, 243.
    specification for, 246, 247.
    stone used, 242.
    suitability of, 242.
    wear, 246.
Stoneware pipes, cost, weights, 279.
Straight line section, metalled roads, 160.
Streets, construction cost, 187.
    drainage, 41.
    width, 40.
Subdivision of private property, 41.
Sub-drainage, 77, 78.
    necessity, 157.
    specification, 104.
Subsidence of embankment, 61, 62.
Suburban streets, cross sections, 163-169.
Surveys, final, 60
    trial, 57-59.

Swampy ground, roads in, 65.
Sweeping machines, 199.
  combination, 201.
Sweeping and watering machine, 201.

T.

Tacheometer, use of, 59.
Tallow-wood wood blocks, 228.
Tamping, roller, 95.
  rod, 136.
  shot holes, 136.
Tar, distillation of, 205.
  treating, 205, 206.
  quality, 204, 209.
Tarring of metalled roads, applying tar, 205.
  applying tar by machinery, 206.
  cost, 208.
  durability of, 207.
  dust prevention, 257.
  quality of tar, 204, 208.
  suitability of road, 204
Tar macadam, advantages, 214.
  cost, 213.
  disadvantages of, 226, 227.
  drying of metal; 210.
  Gladwell's method, 212, 213.
  laying, 211.
  maintenance, 214.
  maximum gradient for, 215.
  mixing of, 210.
  quality of tar, 209.
  quantity of tar, 211.
  rocks suitable, 209.
  rolling, 211.
  tarring after spreading, 212, 213.
  tarmac, 209.
Tar pavement, cost, 187, 266.
  durability, 266.
  season for, 196.
  specification, 264, 265.
  suitability, 264.
  width, 260.
Tar-spraying machinery, 206.
Taxation, insufficiency of, 32, 33.
Telford pavement, 152, 153.
  advantages, 155, 156.
  cost, 184.
Temporary v. permanent works, 15-19.
Tenders (see contracts).
Tender form, 308.
Tendering, conditions of, 309-311.
Tests of road metal, abrasion, 219.
  laboratory, 129.
  by Mr. Lovegrove, 129, 130.
  by Mr. Page, 129.
  traffic, 129.
Thickness of metal, 168-171.
  formula, 171.
  maintenance, 198.
Timber, culverts, 286-289.
  kerbs, 263.
  wood pavement, 227-229.
Tires, iron and rubber, 3.
  pneumatic, 3.
  wide, resistance, 3.
Tires, width of, advantages of wide, 27.
  formula for computing width, 29.
  increasing the width, 27.
  limiting loads in various places, 27-29.
  minimum, 29.
  rebate for wide tires, 29.
  table of widths in England, 29.
Topographical features, 48.
Town streets, cost, 187.
  cross sections, 163-169.
  location, 40, 41.
  varying levels, 162.
  width, 40.
Township design, drainage lines, 41.
  levels important, 41.
Tram lines in forest country, 24.
Tram plate lines, economics, 21, 22.
  construction, 250.
  cost, 251.
Tramways, electric, on roads, 22, 23, 165-167.
Traction engines, flexible wheels for, 192.
  grippers on, 192.
Traction, resistance to, 1-6.
Tractive force, table I., 4.
Tractive resistance on level, 3.
Traffic, volume of, 193.
Transport of earth, 67.
Trees on roads, advantages, 24.
  disadvantages of, 24.
  planting of, 25.
  position of, 163.
  spacing, 25.
  varieties, 25, 26.
Trèsaguet road, 170.
Trial surveys, 57-59.
Trimming of flanks, 198.
Trinidad asphaltum, 219.
  cost for footpaths, 269.
  for footpaths, 269.
  gradients suitable, 225.
Tumbler carts for garbage, 202.
Tunnels in road works, 305.

U.

Undulating country, location in, 53.

V.

Val-de-Travers asphalt, 217, 218.
Valley roads, location, 52.
Velocity head, 281.
Vertical angles, conversion to gradients, 50.
Vignoles' rail as a scraper, 92.
Volcanic rocks, 126.
Volume of traffic, 193.

W.

Wages, rates of, 31.
Walls, paparet, 303.
  retaining, 303.
  sea, 187, 188.
Water breaks, 83.
Water carts, 199.
  cost, 200.
  motor, 200.
  sprinklers for, 201.
Watertables, capacity, slopes, 81.
Watering of streets, cost, 256, 257.
  fresh water, 255.
  sea water, 256.
Watering and sweeping machines, 201.

Watering places, on roads, 39, 56.

Waterway of culverts, 275.

Wear, of asphaltum. 221.
  of metalled roads, 193.
  of stone pavement. 246.
  of tarred roads, 207.
  of wood pavement, 227.

Weight, of gravel, 98.
  of rollers, 175.

Wheels. abrasion by. 191.

Wheelways. steel, construction, 250.
  cost, 251.
  economy. 21. 22.

Wide roads, cross sections of, 165-167.

Width of footpaths, 163.

Width of metalling, 99, 161, 162, 165.

Width of roads, channels on roads, 39.
  flat country, 39.
  hilly country. 59.
  rights-of-way, 40.
  stock routes, 40.
  town streets, 40.

Width of tires (see tires).

Wind. effect of on roads, 190.

Woodblocks. cost, 229.
  for sandy ground, 245.
  sizes 229.
  specification, 235.

Wood pavement compared with macadam, 19-21.
  concrete foundation, 229.
  cost, 229, 233.
  cross sections, 230, 231.
  crown, 230.
  drains. 292.
  durability. 232, 233.
  expansion joints. 232.
  gradients suitable, 225.
  laying, 231.
  life. 225.
  sandy roads. 245.
  size of blocks. 229.
  slipperiness, 232.
  specification. 234-239.
  timbers used, 227-229.
  wear of, 227.

Wooden kerbing, 263.

Works, temporary, v. permanent. 15-19.

Wrought-iron kerbs. 263.

Z.

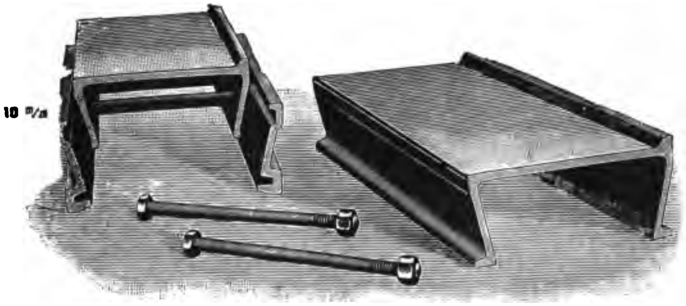
Zig-zags on mountain roads, 58.

McCarron, Bird & Co., Printers, 479 Collins Street, Melbourne.

McCarron, Bird & Co.,
Printers,
479 Collins Street, Melbourne.

LOHMANN & Co.

493 Collins Street, Melbourne.



Patent Steel Road Rails

As Supplied to the Moorabbin Shire Council.

Chief Advantages:

Greater Durability.
Less Cost in Maintenance.
Great Saving in First Cost.

Full Particulars and Estimates on application to

SOLE AGENTS FOR AUSTRALASIA:

LOHMANN & CO.

JOHNS & WAYGOOD

LIMITED.

STRUCTURAL

..ENGINEERS..

Agents Carnegie Steel Company's Structural Material.
American Bridge Company of New York.

……

Girders and Rolled Steel Joists

for Bridges, Culverts, &c.,

Strengths Calculated. ∴ **A SPECIALTY.**

……

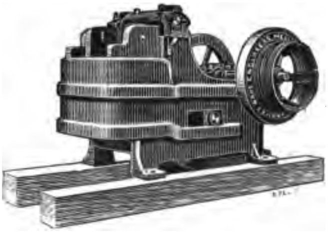
Shire Engineers are invited to ➞
write for information regarding Steel Bridges
before Constructing of Timber.

Makers of TURPIN PATENT SCOOP
for Cleaning Tanks, Dams, &c.

ADDRESS—

Sturt St., South Melbourne.

OUR SPECIALITIES.



Rotary Rock Breakers
(Stationary and Portable).

Horizontal and Vertical Lever Jaw Breakers.
(Stationary and Portable).

Roll Jaw Crushers (For Fine Crushing).

Combined Crusher and Roller Mills.

Laboratory Sample Grinder.

Improved High-speed Roller Mills
(Belt Driven).

Jaques' Standard Elevators.

Revolving Screens.

Conveyors, Rubber Band, also **Steel Strip Conveyors,** or **Picking Tables** and **Spiral.**

We also Contract for COMPLETE PLANTS and supply suitable Plans for erection of same.

Full information will be readily given in respect to all the above-mentioned by

JAQUES Bros., Engineers,

Coppin St., Richmond, Victoria, Australia.

"Coombs" Pneumatic Ejector
for Raising Crude **SEWAGE.**
Estimates given for Complete Installations.

Electric Installations.
Large or Small Plants by
BRUSH ELECTRICAL ENGINEERING CO. LTD

Weighbridges
W. & T. AVERY LTD.
Stocked and Erected.

Rowe, Drew & Co.
550-552 Collins St.,
Melbourne.

"Marshall" Steam Road Rollers.
With and without Scarifiers.

"Marshall" Traction Engines and Road Locomotives.

"Marshall" Portable Steam Engines.

Improved "Hope's" Stonecrushers.

Prices and full particulars on application to—

ROBISON BROS. & COY.
PROPRIETARY LTD,
Normanby Road, Yarra Bank,
ADJOINING GRAVING DOCKS. **South Melbourne.**

BARFORD *and* PERKINS

New Patent

WATER BALLAST MOTOR ROLLERS

Economical in work. Easily managed.
Move either way. Thoroughly tested.
Smokeless and not noisy.

These Rollers are now in regular use in the United Kingdom and abroad for making and repairing roads and pavements of all kinds, for Golflinks, Racecourses, Cricket Grounds, &c.

For Export the Motors can be adapted for paraffin or other heavy oils.

Made in sizes, 2½ to 8 tons, with Interchangeable Main Cylinders for the larger sizes to adapt the roller to the purposes required.

BARFORD & PERKINS,

The Largest Makers of Rollers in the world, and the original Patentees of the Water Ballasting System.

Works: PETERBOROUGH, ENGLAND.

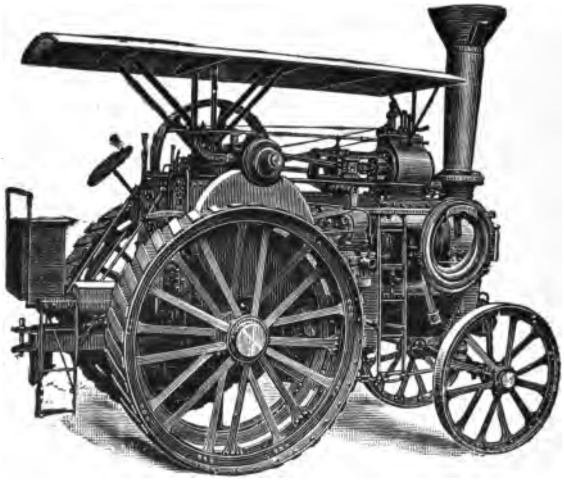
LISTS ON APPLICATION.

WELCH, PERRIN & Co.

Agricultural and General

.. Machinery Merchants..

48-56 Queen's Bridge St., SOUTH MELBOURNE.



SOLE VICTORIAN AGENTS FOR

JOHN FOWLER & CO. (Leeds) Ltd.

Road Rollers and Traction Engines.
Steam Ploughs.

CLAYTON & SHUTTLEWORTH Ltd.

Portable Engines, Thrashing Machines, and Centrifugal Pumps.

PUMPS of every description a Specialty.

AGRICULTURAL MACHINERY of all kinds.

Full Particulars and Catalogues on application.

CLIFF & BUNTING,

Manufacturers of Agricultural Implements and Machines,

FLEMINGTON ROAD, HAYMARKET, NORTH MELB.

MANUFACTURE

Traction Engines, Travelling Chaffcutters.
Interchangeable and Fixed Knife Wheels.
Single and Double Bag Fillers.
Stationary Chaffcutters, with 2, 3, or 4 arm Knife Wheels.
Horse Works, for 1, 2, or 4 horses.
Crushers for Grain. Grinders for Corn.
Sawbenches for Firewood, Ripping and Crosscutting.
Flax and Hemp Machinery. Ensilage Cutters.
Elevators and Blowers. Emery Wheel Stands.

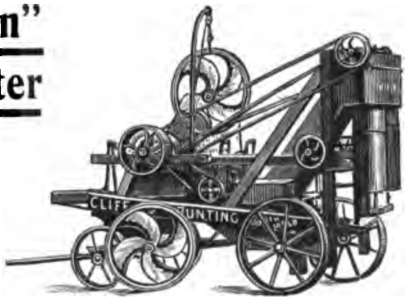
Australian Built Traction Engine.

The Cliff and Bunting is the first Traction Engine manufactured in the Commonwealth. It combines all the best points of the English and the American patterns and has heavy boiler plates, centre crank, all-steel gearing, 2 speeds, through axle, replaceable bearings, large water tank, winding drum on back axle.

The "New Champion" Travelling Chaffcutter

With interchangeable knife wheels, safety steel stop and reversible gear, keen drawing roller, unchokeable cheeks.

The Latest Up-to-date Chaffcutter.



DORMAN, LONG & CO. LTD.

Head Office and Rolling Mills:
MIDDLESBROUGH, ENGLAND.
Victorian Works and Head Office for Australia:
GRANT STREET, SOUTH MELBOURNE.
Manager: T. TIMMINS, A.M.I.C.E.

MANUFACTURERS of Steel Joists, Channels, Troughs, Angles, Tees, Plates, and all Material required for Bridges, Roofs, and Structural Steelwork.

BRIDGE OVER SALTWATER RIVER, MELBOURNE.

COUNTRY BRIDGES—Light, Cheap, and Strong—may best be constructed of Steel Joists, with deck of smaller Steel Joists embedded in Concrete. Consult us.

Large and complete Catalogues on application.
Designs and Estimates FREE.

Telephone Nos. 2096 & 4613.

The Austral Otis Engineering Co. Ltd.

MANUFACTURERS
of all Classes of

MODERN MINING and ROAD-MAKING MACHINERY.

Steam Rollers, Traction and Portable Engines, Excavating Machinery.

Rock Breaking, Crushing, and Screening Machinery.

Roasting and Smelting Furnaces.

Steam and Electric Pumping and Winding Machinery.

Air Compressors. Rock Drills. Boilers.

Mining Requisites of every Description.

Middleton, Cobb and Bigelow Grinding Pans.

Plans & Specifications prepared and Estimates submitted for complete Mining Plants.

Correspondence Invited.

SOUTH MELBOURNE, Victoria.

QUARRYING MACHINERY

of Every Description.

THE

Ingersoll-Rand Co.

MAKE

ROCK DRILLS

FOR EVERY SERVICE.

The type illustrated will do any kind of work.

It may be mounted on tripod, column bar, quarry bar, or quarry gadder.

Sergeant Rock Drill with Adjustable Tripod.

THE

Sergeant Drill

is the most powerful and most effective machine on the market.

It is also the most economical in air or steam consumption and up-keep.

All Sizes are kept in Stock at Melbourne for immediate delivery, as well as Spare Parts.

IMPROVED QUARRY BAR.

To put in a line of holes you simply move the Drill along the Bar.

When drilling close to a bench the end piece may be slipped in and the Drill mounted on projecting Bar (as shown).

AIR COMPRESSORS

All Sizes to 1500 feet carried in Stock in Australia.

If you are interested in Quarrying or Mining write for our complete illustrated Catalogue.

INGERSOLL-RAND CO.

HEAD OFFICE FOR AUSTRALIA— 41 QUEEN ST., MELBOURNE.

For ROAD MAKING and LAND CLEARING

USE

Nobel-Glasgow Explosives,

Gelignite, Gelatine Dynamite, Blasting Gelatine, Electric Detonator Fuses, Rackbar Exploders, &c.

Messrs. Nobel's Explosives Co. Ltd.

is represented throughout the Commonwealth and New Zealand by the following firms:—

Dalgety & Co. Ltd., Melbourne.
Dalgety & Co. Ltd., Sydney.
Brabant & Co., Brisbane.
Elder, Smith & Co. Ltd., Adelaide.
Elder, Shenton & Co. Ltd., Fremantle.
Hendrie & Bell, Port Darwin.
E. Porter & Co., Auckland.
Dalgety & Co. Ltd., Dunedin.
J. S. Munro & Co., Zeehan.
W. Hart & Sons, Launceston.
W. M. Bannatyne & Co. Ltd., Wellington.

Write for Illustrated Pamphlets with Instructions.

Mr. ARNOLD LILLY

(Late Scholar of Clare College, Cambridge, and Stawell Exhibitioner, Matriculation Exhibitioner, Mathematical Exhibitioner, First-class Honourman and Prizeman of the Melbourne University).

Undertakes to Prepare Surveyors and Civil Engineers

FOR THE

Authorised Surveyors' Examination,
Municipal Surveyors' Examination,
Hydraulic Engineering Examination,
Mining Surveyors' Examination

Of Victoria, and for the Survey and Engineering Examinations of the adjacent States.

FEES at the rate of ***5s. per hour,*** or per letter if by correspondence. Payable ***Monthly in Advance.*** Either one or two letters per week forwarded as desired.

The system of preparation adopted is to work almost entirely from the actual Papers of the Previous Examinations, extending back for the last ten years, in the cases of the Municipal and Authorised Surveyors' Examinations.

Special attention given to ***Bridge-work and Hydraulics*** in Engineering and to ***Star-work*** in Surveying.

All Correspondence Strictly Private and Confidential.

138 ALBERT ROAD, SOUTH MELBOURNE.

Telephone 134 City.

JAMES FORBES & CO.

ASPHALTERS AND TAR DISTILLERS,

Manufacturers of Tar and Carbolic Oils,

SOLE MANUFACTURERS OF FORBES' ASPHALT.

Importers and Layers of Trinidad Asphalt, Seyssel, Val de Travers and Limmer Asphalts.

Manufacturers of Bitumen Paint, Bitumen Compound, Plumbers' Bitumen, Naphtha, Varnish, Coal Tar Pitch, Salts, Creosote, Carbolic Oils, and Phenyle.

Tar Paving at Lowest Rates.

Distilled Tar supplied in any quantity.

Office and Works:

MUNRO & BRADY STS., STH. MELBOURNE.

Kilpatrick & Co.

have the LARGEST STOCK of

Surveying and Drawing Instruments.

They Sell the FINEST QUALITY in all Lines.

Indent any Instrument not Stocked and keep the most Expert Workmen for New Work or Repairs.

LISTS OF PRICES sent on application.

358 COLLINS STREET,
MELBOURNE.

The fact that your C.I. Pipe & fitting requirements are exacting, is all the more reason why you should use

DANKS' MAKE

Sluice Valves and Covers, Cast Iron Pipe and fittings, Pillar Hydrants, Inspection Boxes, Fire Plugs and Covers, Air Escape Valves for Mains, &c., &c.

CONTRACTORS TO
VICTORIAN WATER SUPPLY, MELB. & MET. BOARD OF WORKS, SYDNEY WATER SUPPLY, &c.

JOHN DANKS & SON Prop. Ltd.

391 Bourke St., Melb. **324-30 Pitt St., Sydney.**

STEWARTS AND LLOYDS LTD.

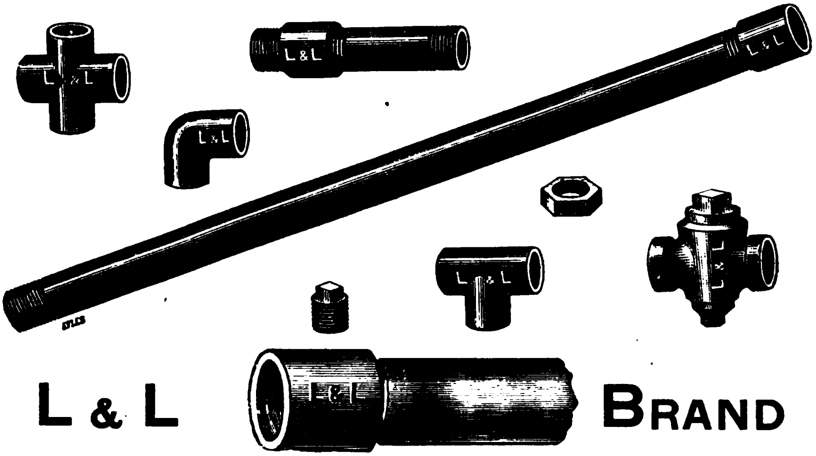
HOLD LARGE STOCKS OF

Wrought Iron Tubes and Fittings

. . . FOR . . .

Water, Gas, Steam, Hydraulic, Irrigation

and other purposes.



L & L BRAND

Unequalled for QUALITY, SCREWING, and FINISH.

Boring Tubes and Casing Largely Stocked.

... ALSO ...

Our "Clydesdale" Brand of Steel Plates in all sizes.

Melbourne Store and Office:

Box G.P.O. No. 319. **95-101 QUEEN'S BRIDGE ST.**

Brisbane Store and Office:

Box G.P.O. No. 309. **97 & 99 GEORGE STREET.**

For all
Building Purposes

USE

"ORB" Galvanized Corrugated Iron

Price and Quality Always Right.

Every Sheet Guaranteed.

OBTAINABLE FROM ALL

Storekeepers, Timber Merchants, and Ironmongers

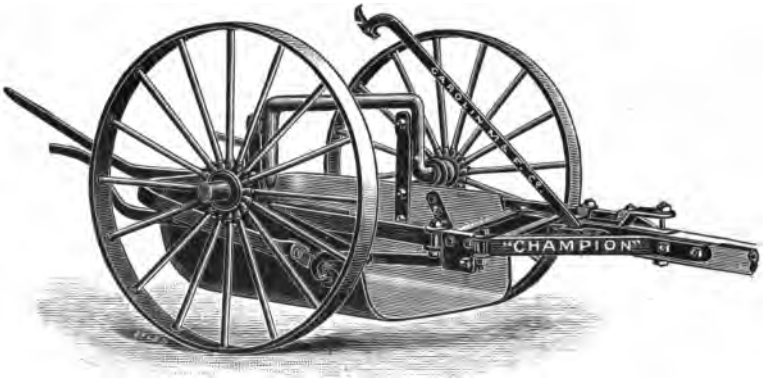
THROUGHOUT AUSTRALIA.

"Champion" Road Making and Earth Moving Machinery and Implements.

MFD BY AMERICAN ROAD MACHINE -Co- KENNET SQ U.S.A.
CHAMPION MOUNTED BIN

The "Champion" Complete Portable Rock Crushing Outfit, with Mounted Bins.

The only strictly portable plant made. May be stopped on the road and started crushing within two minutes. Built almost entirely of Steel, and will last a lifetime.



The "Champion" Wheeled Scoop, with Steel Wheels,
Is the Ideal for moving earth; furnished with automatic end gates. Bowl pressed out of best steel; capacities—10, 13 and 17 cub. ft.

Beware of Imitations. None are genuine without this Trade Mark.

Examine our stock of Rock Crushers, Road Machines, Road Ploughs, Steel Reversible Road Rollers, Elevating Graders and Waggon Loaders, Metal Distributing Carts, Portable, Traction, and Stationary Oil Engines. We give a written guarantee with all our Goods.

Write for Catalogues and Testimonials.

CAROLIN MACHINERY & F. CO.,
MELBOURNE, SYDNEY, & BENDIGO.

THE REINFORCED CONCRETE and MONIER PIPE Construction Company Pty. Ltd.

OFFICE:

Oliver's Lane, Melbourne.

FACTORY:

Burnley Street N., Richmond.

THE Company prepares Designs and submits quotations for all classes of Municipal Engineering Construction in **Reinforced Concrete.**

This Material provides Permanent Construction—proof against fire, corrosion, decay, or deterioration in any form whatever—and at moderate cost.

Our Specialities are: — **Road Bridges, Road Culverts** from 9-in. up to 6-ft. diameter, all sizes up to 3-ft. diameter, having **complete culvert fronts;** also **Kerbing, Channelling, Flagging, Portable Flat Decks** to **Culverts** and **Small Bridges; Stormwater Drains; Water Troughs, Tanks, Reservoirs,** and **Standpipes.**

Municipal Officers are invited to submit full particulars of their requirements, when propositions will be promptly submitted.

"UNION" CEMENT

MANUFACTURED BY

THE COMMONWEALTH PORTLAND CEMENT CO. LTD.

HEAD OFFICE: MUTUAL LIFE OF NEW YORK BUILDING, MARTIN PLACE, SYDNEY.
WORKS: PORTLAND, NEW SOUTH WALES.

As supplied to the Melbourne and Metropolitan Board of Works, Victorian Railway Commissioners, Public Works Department and Railway Commissioners of New South Wales, &c., and to the leading Building Contractors, Engineering and Mining Companies in Australia.

AGENTS IN ALL THE STATES.

Representative for Victoria: Mr. RICHARD TAYLOR, 31 Queen Street, Melbourne.

RICHARD TAYLOR

31 Queen Street, Melbourne.
Pipe Works: Port Melbourne.

MANUFACTURER OF

Reinforced Concrete Pipes IN ALL SIZES.

ALSO

Kielberg Cement Concrete Pipes.

One and a-half Million feet of Keilberg Pipes have been used in the Sewering of Melbourne by the Melbourne and Metropolitan Board of Works, also in the Sewering of Rockhampton, Launceston, Dunedin, and other Towns.

JARRAH

Australia's Best Hardwood.

Unequalled for Piles, Beams, Sleepers, Trucks, Telegraph, Telephone and Lighting Poles, Fencing, Builders' Scantling, Paving Blocks, &c., &c.

JARRAH Resists Teredo and White Ants.

JARRAH is not affected by Damp or Dry Rot.

JARRAH PAVING BLOCKS

Make the Best Roads, and are extensively used in London, Melbourne, Adelaide, Wellington (N.Z.), Perth and Fremantle (W.A.).

(Read Chapter II. on Wood Paving).

MILLARS' KARRI & JARRAH CO. (1902) Ltd.

NOTE OUR ADDRESSES:

PERTH, West Australia.
SOUTH MELBOURNE, Victoria.
SYDNEY, New South Wales.
SOUTH BRISBANE, Queensland.
Auckland, Wellington, Christchurch, and Dunedin (N.Z.).

HEAD OFFICE:
72 BISHOPSGATE ST., WITHIN, LONDON, E.C.

JOHN SHARP & SONS

AUSTRALASIAN

Steam Joinery, Saw Planing, and Moulding Mills,

City Road, South Melbourne.

In Stock and on Sale

. . at Current Rates . .

Michigan and Californian Red and White Pine, Lumber and Shelving.
Baltic Deals and Battens, solid and cut.
Oregon and Kauri Beams, solid and cut.
Redgum Logs, Beams, Planking and Fencing.
Tasmanian Blackwood and Hardwood, in log and plank.
Cedars, in log and boards; Turnery.
Norwegian Red and White Flooring, Lining and Weatherboards.
American and Colonial Doors, Sashes and Windows complete.
Architraves, Mouldings, Skirting, Anglebeads, &c.
Galvanised Iron, 5 to 10 feet; Spouting and Ridging.
Builders' Ironmongery, Sashweights, White Lead and Oils.
Portland Cement, Plaster of Paris, Laths, Fireclay and Firebricks.
Redgum Felloes, 5 and 6 ft. Palings and Pickets.

And every description of Building Materials for Town and Country Trade.

Joiners' Work made to order.

THE NEUCHATEL ASPHALTE CO. LTD.

Sole Concessionaires of the

VAL DE TRAVERS

ASPHALTE MINES.

Val de Travers Compressed Asphalte Roadways are Sanitary, Durable, Economical.

VIEW OF QUEEN STREET, AUCKLAND.

Area asphalted, 28,000 sq. yards. Laid in 1902 by the Neuchatel Asphalte Co. Ltd. with Compressed Asphalte. This roadway is guaranteed for 20 years.

Roadways constructed by the NEUCHATEL ASPHALTE Co. Limited in Australasia:—Queen St., Shortland St., High St., Railway Wharf, and Queen Street Wharf, Auckland (N.Z.); Post Office Square and Rattray St., Dunedin (N.Z.); Watt St., Newcastle (N.S.W.); and Commercial Road, Prahran, Melbourne.

The Neuchatel Asphalte Co.'s Australasian Head Office:

395-7 COLLINS ST., MELBOURNE.

A. B. WOOLF, General Manager.

Permanent depots in all cities throughout the Commonwealth and New Zealand.

To all interested in

Roadway and Footpath Construction.

We invite enquiries re our System of

GRANOLITHIC PAVING

EXTENSIVELY USED FOR

ROADS, FOOTPATHS, KERBING, CHANNELING, &c.

Also a thoroughly **Sanitary** and **Durable** Material for all **Flooring purposes** and **Yard areas.**

Laid in position in red, slate or grey colour, or supplied in slabs of convenient size for laying.

PARTICULARS ON APPLICATION—

Granolithic Patent Paving Coy.

PROPRIETORS:
A. H. VINCENT.
GEO. VINCENT.

57 a'BECKETT STREET,
TEL. 2383. MELBOURNE.

ASPHALTING.

◆◆◆◆◆◆

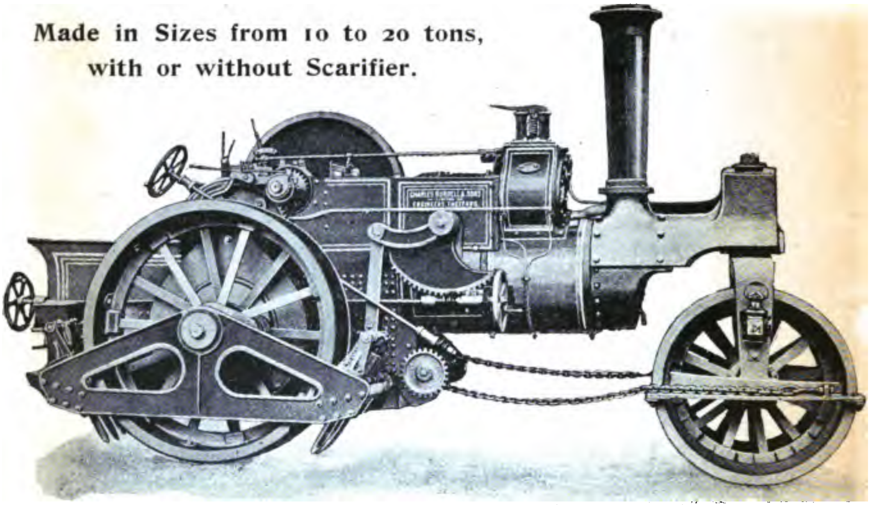
WM. SIM,

Limmer, Trinidad, Pitch, Damp Course, Tarpaving,
Tennis Courts and Fences.
Innes' Granolithic Paving.

Nolan and Dodd Sts., South Melbourne

TEL. 3586.

Burrell's Improved Patent Steam Road Roller and Scarifier.



Made in Sizes from 10 to 20 tons,
with or without Scarifier.

BURRELL'S

World-Famed Patent Steam Traction Engines

Excel all others for driving Thrashing Machines, Hauling and Ploughing. They are more Powerful, Economical, and Easier Handled than any other.

E. COULSON,

Sole Agent for Burrell's Road Rollers, Road Locomotive and Patent Steam Traction Engine.

And Patentee and Manufacturer of the SIMPLEX OIL AND GAS ENGINES.

106 to 116 a'Beckett Street, Melbourne.

McCarron, Bird & Co., Printers and Lithographers, 479 Collins Street, Melbourne.

791 10\04 30
39950 BUI

b89090506338a

89078537552

b89078537552a

K.F. WENDT LIBRARY
UW COLLEGE OF ENGR.
215 N. RANDALL AVENUE
MADISON, WI 53706